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## The Great Basin Naturalist 50-YEAR INDEX

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### PREFACE

For the past 50 years, the *Great Basin Naturalist* has published results of natural history studies in the intermountain region. Vasco M. Tanner, a protégé of David Starr Jordan, deserves recognition for establishing the journal, maintaining it, and securing its good reputation for the first 30 years. (More information concerning Dr. Tanner and his contributions can be found in Vol. 30, No. 4.) The *Great Basin Naturalist's* second editor, Stephen L. Wood, continued to promote its growth and recognition for the next 20 years. Since September 1989 James R. Barnes has been the editor. Very few regional natural history journals can claim the distinction of having survived for half a century and having had only two editors during that time.

Today the *Great Basin Naturalist* is firmly established as a forum for reporting research; its contents exhibit a range of emphasis in natural history topics and methods. In the earlier years papers centered on descriptive

research, while later papers have more often been analytical. Both early and more recent studies continue to be utilized, providing invaluable groundwork for further synthesis and new conclusions.

Volume indices, printed at the end of each year, have facilitated finding what has been published in the journal. A 30-year index was compiled by Vasco M. Tanner when he retired as the first editor. Basically an author-title index with a comprehensive listing of new taxa, it was very helpful in locating information from that time period. Since then only volume indices have been published. Before Stephen L. Wood retired, he felt it would be valuable to compile a 50-year index to the *Great Basin Naturalist*. The authors of this index approached Dr. Wood and offered to do the work on the project. As life science librarians, we recognized the benefits such an index could provide.

Our intent in creating this index is to enable researchers to readily locate articles of interest, descriptions of new species, and other

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information contained in the past 50 volumes of the *Great Basin Naturalist*.

## INTRODUCTION

This index consists of two parts. The first is an author-title index. Entries are alphabetical (last name first) by senior author with cross references from secondary authors to the senior author. Under an author's name, articles written solely by the author are listed first; articles with one co-author come next and are followed by articles with two or more co-authors. Co-authors are listed in the order they appear on the title page of the article. Example:

Cottam, Clarence, Cecil S. Williams, and Clarence A. Sooter. Some unusual winter visitors or late migrants to the Bear River marshes, Utah. 3:51-53.

Sooter, Clarence A. *See* Cottam, Clarence 3:51-53.

Williams, Cecil S. *See* Cottam, Clarence 3:51-53.

The second part is a subject index. Most articles received three or four subject entries. These terms were taken from the title and abstract and were sorted so that each significant term became a main heading. The other subject terms used for each article are listed as subheadings under the main headings to help locate specific articles. Following each entry are the *Great Basin Naturalist* volume and page numbers where the article can be found.

In indexing names of plants and animals we used the following guidelines:

(1) If both Latin and English names appeared in the title or abstract, both were used in the index, except in most taxonomic articles. In taxonomic articles the Latin names took precedence.

(2) If only Latin names were present in the title or abstract, then only Latin names were used in indexing.

(3) If only English (common) names were in the title or abstract, then only those were used in the index.

When indexing taxonomic articles, we primarily used only Latin names. Articles were indexed according to the lowest taxonomic group that included all taxa discussed. Additional entries were made for all new genera, species, subspecies, or varieties. Also, entries

were generally made for class in vertebrates, order in invertebrates, and family in plants. The new portion of the name was then set in boldface type in lieu of other designations such as n.sp. Example (brackets [ ] indicate intervening entries):

Acari

*Ametroproctus*, systematics, United States 25:44-46

[ ]

*Oppia coloradensis*, systematics, Colorado 29:133-136

*Ametroproctus oresbios* 28:44-46

*Oppia coloradensis* 29:133-136

New combinations were not indexed due to space limitations. New records received one entry per article unless only two names were listed. When only two new records were given, they each received a separate entry. All new records can be found under the heading "New records," followed by the name (usually in Latin) and then locality. Checklists were designated by subheadings under the group name and/or location of the checklist. Keys were indexed in this same way. Example:

New records

[ ]

*Hindia sphaeroidalis*, Nevada 36:206-210

Plants

[ ]

Vascular

[ ]

Bighorn Canyon, Wyoming-Montana, checklist 45:734-746

Polygonaceae

[ ]

*Eriogonum pauciflorum*

Systematics, keys 27:102-117

Geographic names were used as main headings whenever they were significant to the article. State or region was followed by the locality within that area. Example:

Nevada

[ ]

Pyramid Lake

[ ]

Sacramento perch, life history 41:278-289

An additional main entry was made for the locality name followed by the state or region. When a geographic name was used as a subheading, the locality was always listed first, followed by the state or region. Example:

Pyramid Lake, Nevada

[ ]

Sacramento perch, life history 41:278-289

Subject headings beginning with arabic numbers (i.e., 2,4-D) are listed after the Z's at the end of the alphabetic terms.

Many multiple-term main headings were inverted to place related topics in closer proximity. This applies primarily to English names of organisms, general subjects, and geologic time periods. Example:

Grouse

Blue

Effects of summer weather on harvest 42:91-95

Feeding habits 46:123-127

Hatching chronology 46:745-748

Sage

Big sagebrush, selection 48:274-279

Habitat use by breeding males 49:404-407

No attempts were made to control vocabulary and nomenclature in creating the index. The terminology employed by authors in titles and abstracts was used in the index, except in systematic articles where we used the term systematics to include taxonomy, descriptions, etc.

We hope the index will be accurate, easy to use, and helpful in finding the valuable information published in the first 50 volumes of the *Great Basin Naturalist*.

#### ACKNOWLEDGMENTS

Special acknowledgments are due the Harold B. Lee Library administration and the School of Library and Information Sciences for providing the time and facilities for preparation of this index. Student research assistants Jessica Draper, Charles Kahua'u, Elizabeth Slaughter, Anna Wu, and Zhang Limin spent many hours proofreading and making corrections. Erva Rieske and her students in the library secretarial pool entered data for the author/title index. Kal Larsen, of library computer operations, provided invaluable computer programming. The authors express their appreciation to each of these people who made an arduous task easier.

# PART I

## AUTHOR-TITLE INDEX

(To determine the year of publication, add 1940 to volume numbers beginning with volume 10. During World War II publication of the *Great Basin Naturalist* was, of necessity, less structured. Consequently, some early volumes cover more than a year; others are limited to one issue consisting of the four quarterly numbers. Consult a library for accurate publication dates for volumes 1-9.)

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## EVOLUTIONARY DIFFERENTIATION WITHIN THE NORTHERN GREAT BASIN POCKET GOPHER, *THOMOMYS TOWNSENDII*. I. MORPHOLOGICAL VARIATION

Mary Anne Rogers<sup>1</sup>

**ABSTRACT.**—Geographic and nongeographic variation in morphology was examined in *Thomomys townsendii*. A univariate analysis of external and cranial characters from a large population sample (66 adults; fusion of cranial sutures used as aging criteria) was used to assess variation among three adult age classes and between sexes. Only minor variation is apparent among age classes; however, sexual dimorphism is pronounced. Univariate and multivariate techniques were used to analyze external and cranial measurements and pelage characters for adults throughout the species range. These analyses show little to support the seven subspecific designations recognized by Davis (1937). The general pattern is one of homogeneity throughout the range of *Thomomys townsendii*. With the possible exception of *T. t. nevadensis* samples, current subspecies are not defined as morphological units. In fact, differentiation is found among populations within some subspecies. The most apparent pattern seen in these analyses is the divergence between the Humboldt River (including Honey Lake Valley samples) and Snake River systems. These results will be considered with those of a companion paper on the genetic variation in this species to more adequately assess the patterns of differentiation in *Thomomys townsendii*.

**Key words:** *Thomomys townsendii*, pocket gophers, morphological variation, geographic variation, sexual dimorphism.

For many years pocket gophers of the genus *Thomomys* have been examined and discussed in the context of their tendency to differentiate. In his monograph on *Thomomys*, Bailey (1915) detailed the biology of this "plastic group," including variation in body size and coat color, and correlated environmental factors such as soil color and texture. He noted the correspondence of the limits of many races with physiographic features or climatic areas.

Relationships between the topographic and climatic diversity of California and its numerous forms of pocket gophers were considered by Bailey (1915) and in greater detail by Grinnell (1927). Grinnell cited the fossorial nature

of pocket gophers and their relative inability to disperse over land as biological factors affecting isolation and differentiation of gopher populations. He cited unsuitable soils (such as lava flows), rivers, and insufficient food resources characteristic of dry or alkaline areas as environmental factors that isolate populations from one another. Distribution of the different forms often adheres to altitudinal or climatic boundaries, and features distinguishing these races reflect the nature of the habitat in which they are found.

Since these early studies, investigators have continued to focus on defining and understanding morphological variation within the family Geomyidae. A variety of factors has

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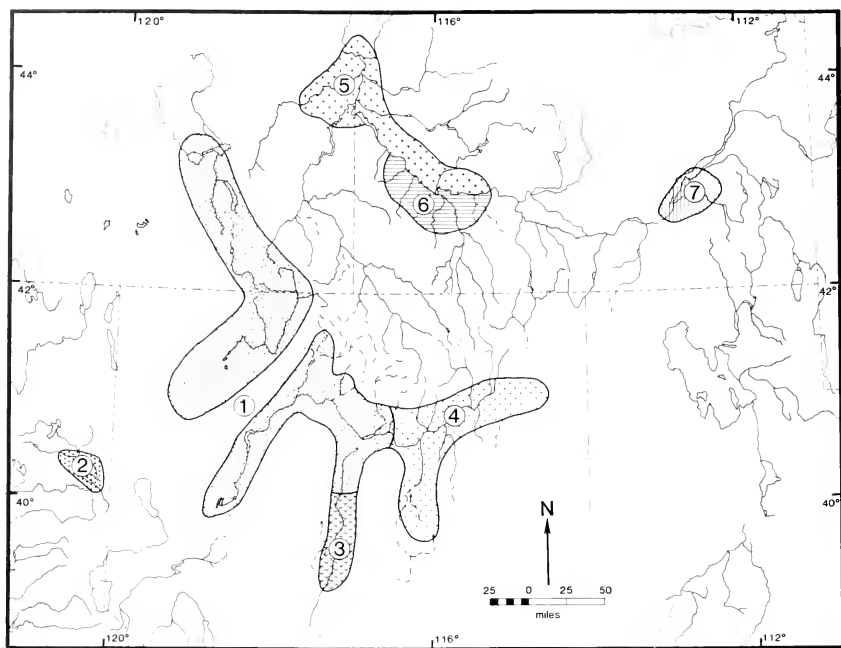


Fig. 1. Map of the present distribution of *Thomomys townsendii* modified from Davis 1937 and Hall and Kelson 1959: 1, *T. townsendii bachmani*; 2, *T. townsendii relictus*; 3, *T. townsendii nevadensis*; 4, *T. townsendii elkoensis*; 5, *T. townsendii townsendii*; 6, *T. townsendii owyhensis*; 7, *T. townsendii similis*.

been discussed as possible determinants of the patterns of variation seen among populations, subspecies, and species of pocket gophers (Davis 1938, 1940, Ingles 1950, Thaeler 1968, Smith and Patton 1980, 1988, Patton and Brylski 1987, Patton and Smith 1989). Davis (1938) found size in *Thomomys* to be directly correlated with soil conditions and inversely correlated with elevation. In addition to establishing that larger forms of *Thomomys* are found in deeper soils at lower elevations, Davis also found that larger gophers are more sexually dimorphic. A recent study by Patton and Brylski (1987) demonstrates that body size and sexual dimorphism in pocket gophers are strongly influenced by the nutritional value of their food, while variation in shape is more likely to reflect genetic changes.

Davis (1937) examined morphological differentiation across the range of *T. townsendii*.

This species of pocket gopher is discontinuously distributed through northeastern California, northern Nevada, southeastern Oregon and southern Idaho (Fig. 1), where its range is restricted to deep lacustrine or fluvial soils. Discontinuities in the distribution reflect barriers in the form of expanses of unsuitable desert soils and lava flows and the presence of competing gopher species. Davis (1937) identified these features in his analysis of *T. townsendii* and indicated their importance in influencing the differentiation of the species into the seven subspecies recognizable on the basis of morphological characters.

This study examines variation in external and cranial characters both within and among populations of *Thomomys townsendii* and compares these patterns to the results of Davis's study. In a companion paper (Rogers 1991) results of genetic analyses are also considered. To help explain the resulting

patterns of differentiation, the analysis draws from information regarding the biogeographic history of the area, aspects of gopher population biology, and evolutionary relationships within the genus *Thomomys*. The morphological differentiation and taxonomy outlined by Davis (1937) are reexamined in the context of patterns of morphological and genetic differentiation shown in these analyses.

## MATERIALS AND METHODS

### Aging Criteria

An age category, based upon the degree of fusion of the basioccipital/basisphenoid and the supraoccipital/exoccipital sutures of the skull (Hoffmeister 1969, Honeycutt and Schmidly 1979, Patton et al. 1979), was assigned to each of 628 individuals examined. Each suture was scored on a scale of 1 to 3, with 3 being the most complete stage of fusion. The scores for the two sutures of each individual were then summed to arrive at an age-class value for each individual. The utility of these aging criteria was tested by examining the correspondence of the age categories to molt stage and body size. The large sample from Honey Lake Valley was used to minimize any geographic component of the variation. Males and females were treated separately due to the marked sexual dimorphism often found in geomyids (Merriam 1895, Bailey 1915, Hoffmeister 1969, Honeycutt and Schmidly 1979, Patton et al. 1979). For analyses of interpopulation variation the remaining population samples were also categorized based on cranial suture criteria. Only specimens judged to be adults were used in subsequent morphometric analyses, with the exception of juveniles in adult pelage, which were used only in the analysis of pelage coloration.

### Analysis of Morphological Characters

A total of 477 adult *Thomomys townsendii* were measured for analysis of morphometric variation. In most instances localities were pooled based on geographic proximity in order to increase sample sizes. The resulting 31 composite localities are shown in Figure 2, and their component localities are listed in the Appendix. All localities were included in analyses of interpopulation variation. The two Honey Lake Valley localities were used to examine aspects of nongeographic variation.

Four external and 28 cranial measurements were recorded for each individual. Total length (TOL), tail length (TAL), hind foot length (HFL) and ear height (EH) were recorded directly from the skin tag of each specimen. Cranial dimensions were measured with dial calipers. These measurements, illustrated in Figure 3, are as follows: occipito-nasal length (ONL), basilar length of Hensel (BAL), zygomatic breadth (ZB), mastoid breadth (MASB), interorbital constriction (IOC), rostral length (RL), nasal length (NL), rostral width (RW), diastema length (DIAS), palatal width (PALW), bullar length (BUL), rostral depth (RD), cranial depth (CRD), frontal length-total (FRLT), width foramen magnum (WFM), height foramen magnum (HFM), frontal length-medial (FRLM), dorsal length orbit (DLO), ventral length orbit (VLO), braincase depth (BRCD), width premaxillary tongue (PMXT), premaxillary width (PMXW), length maxillary mortise (MAXM), tooth row length (TRL), depth jugal (DJUG), length anterior edge jugal (LAJ), breadth zygomatic arch (BZA), and distance of procumbancy (DPRO).

A subset of 128 specimens in adult pelage were selected for color analysis. These individuals represented both the geographic range (Appendix) and the variety of pelage colors visible among the available samples for each of the seven subspecies. Albino and melanic individuals were excluded from the analysis. To increase sample size, the 31 localities used in the morphological analyses were grouped by geographic proximity into 13 units and assigned alphabetical designations, A-M.

Variation in mid-dorsal pelage coloration was quantified using a Bausch and Lomb Spectronic 505 recording spectrophotometer equipped with a visible reflectance attachment (for details of colorimetric techniques see Bowers 1956, Selander and Johnston 1967, and Genoways 1973). For each animal, trichromatic coefficients ( $x$ ,  $y$ , and  $z$ ) were derived from curves of percentage reflectance. Values for percent brightness (= value), dominant wavelength (= hue), and percent excitation purity (= chroma) were calculated from these coefficients.

### Statistical Methods

The Statistical Package for the Social Sciences (SPSS, Nie et al. 1975), versions of

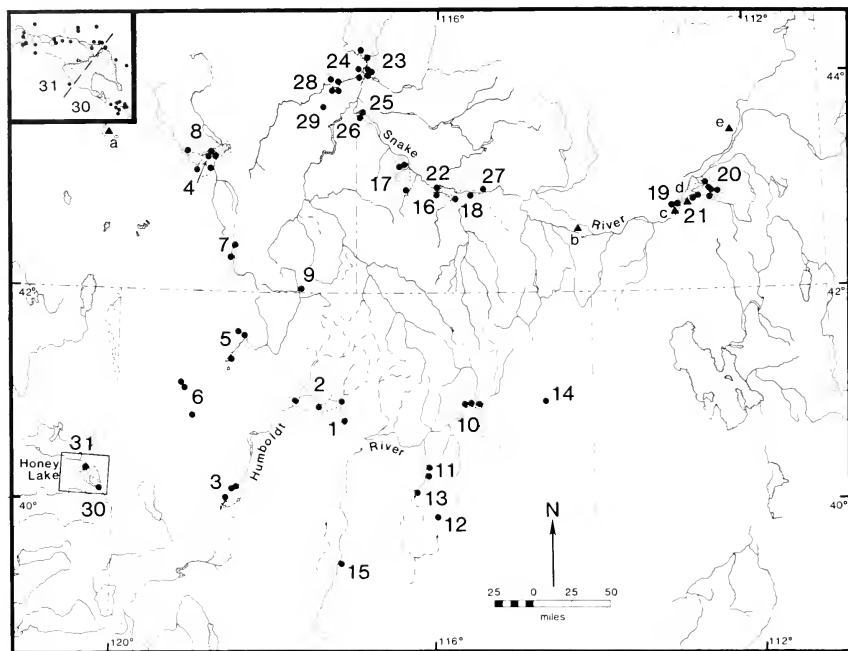


Fig. 2. Map of samples for morphological analysis (circles) and sites from which fossil material of *Thomomys townsendii* has been found (triangles). Inset shows detail of distribution of localities within the Honey Lake Valley. Locality information for recent material is given in the Appendix. Fossil localities are as follows: (a) Fossil Lake, Lake Co., Oregon (early-mid-Wisconsin; Elftman 1931, Allison 1966); (b) Wilson Butte Cave, Jerome Co., Idaho (late Wisconsin to Recent; Gruhn 1961); (c) American Falls, Power Co., Idaho (Sangamonian; Gazin 1935, Hopkins et al. 1969); (d) Rainbow Beach, Power Co., Idaho (late Wisconsin; McDonald and Anderson 1975); (e) Wasden Site, Bonneville Co., Idaho (late Wisconsin to Recent; Guilday 1969).

ANOVA, and discriminant function analysis were utilized for the analyses. Matrices of  $F$  values generated by discriminant function analyses of cranial morphology were clustered using the NTSYS program of Rohlf et al. (1980) as edited for use at University of California, Berkeley, by T. Duncan. Cranial and external data were analyzed using the University of California, Berkeley, computing facilities. Analyses of the three color variables were performed on the Amdahl 470 at the University of Chicago Computation Center.

In establishing aging criteria,  $t$  tests were used to compare the mean body weight and mean total length of adult and juvenile age classes from the Honey Lake Valley sample. The Honey Lake Valley adults (41 males, 25

females) were examined to assess age and sex components of intrapopulation variation in the 28 cranial and 4 external characters. Two-way ANOVA tables were calculated for each of the 32 variables to determine the extent of variation among adult age classes, to assess secondary sexual variation, and to examine interaction effects.

The extent and nature of variation in each of the 32 morphological characters across the range of *T. townsendii* were examined using one-way ANOVAs. In addition to the statistics generated for the intrapopulation analyses, homogeneous subsets of samples were established by Duncan's multiple range tests ( $\alpha = .05$ ). All adult specimens, representing 31 localities, were utilized for the interpopulation

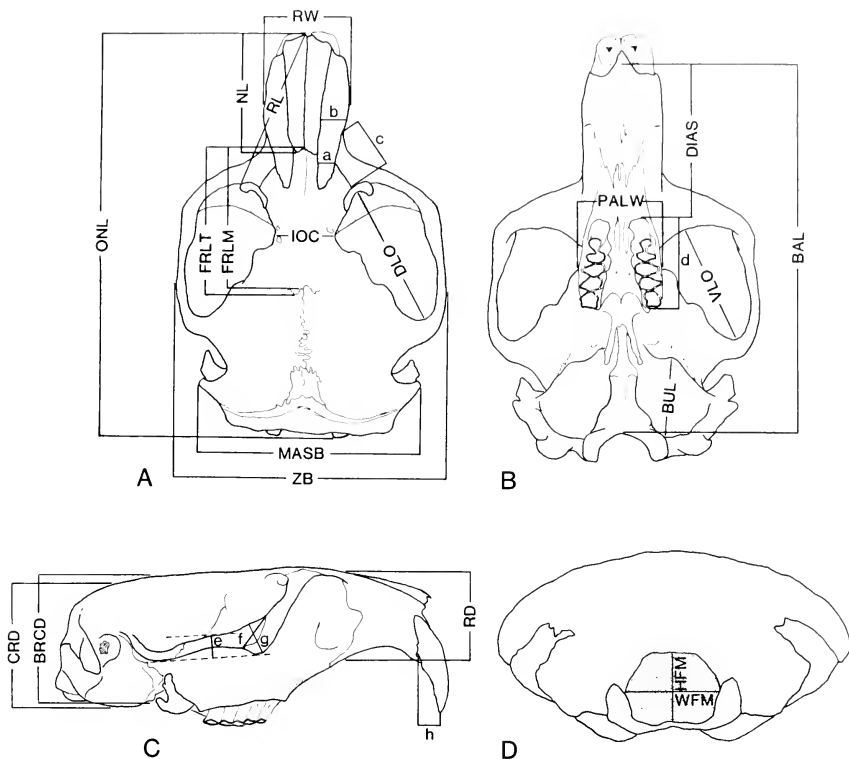


Fig. 3. Twenty-eight cranial dimensions utilized in morphological analysis. Abbreviations correspond to the following dimensions: ONL, occipito-nasal length; BAL, basilar length of Hensel; ZB, zygomatic breadth; MASB, mastoid breadth; IOC, interorbital constriction; RL, rostral length; NL, nasal length; RW, rostral width; DIAS, diastema length; PALW, palatal width; BUL, bullar length; RD, rostral depth; CRD, cranial depth; FRLT, frontal length—total; WFM, width foramen magnum; HFM, height foramen magnum; FRLM, frontal length—medial; DLO, dorsal length orbit; VLO, ventral length orbit; BRCD, braincase depth. Lowercase letters correspond to the following dimensions: a, width premaxillary tongue (PMXT); b, premaxillary width (PMXW); c, length maxillary mortise (MAXM); d, tooth row length (TRL); e, depth jugal (DJUC); f, length anterior edge jugal (LAJ); g, breadth zygomatic arch (BZA); h, distance of procumbancy (DPRO).

comparisons. Since some localities were not represented by both male and female specimens, a total of 30 samples of females and 24 samples of males were analyzed. For clarification, presentation of the results of these analyses may refer to the broad alphabetical locality designations described above, but morphological analyses were performed on the smaller population units.

Multivariate techniques were performed on the 28 cranial measurements for the 30

female and 24 male population samples using discriminant function analysis. Individuals with missing values for any of the variables were excluded from the calculations. A step-wise method was chosen for the entry of the variables into the analysis, using the maximum Mahalanobis distance as the selection criterion. A matrix of *F*-ratios for each pair of groups was calculated after each step, testing the significance of the Mahalanobis distance between groups. Discriminant function

coefficients for each variable and discriminant scores for each individual were calculated. Individuals were plotted two-dimensionally based on discriminant function (DF) 1 and DF2 scores with group centroids indicated. Classification information was provided, indicating the a posteriori probabilities of an individual belonging to its actual group and to the next closest group. Males ( $n = 211$ ) and females ( $n = 266$ ) were treated separately in all univariate and multivariate analyses.

Pelage data (values obtained for brightness, wavelength, and purity) were subjected to similar univariate and multivariate analyses, except that four different grouping schemes were employed in order to define regional patterns of pelage variation. Data were grouped by locality (1–31), by locality groups (A–M), by subspecies, and by major geographic region (Humboldt River, Snake River, Honey Lake Valley). Each grouping scheme was treated separately for each analysis.

## RESULTS

### Aging Criteria

Results obtained from Honey Lake Valley animals indicate that the adult age category, based on cranial suture criteria, is well differentiated by body weight and total length from the juvenile category. *T* tests show the two age categories (classes 1–3 and 4–6) differ significantly ( $P < .05$ ) in body weight and total length. Examination of molt stages of individuals from Honey Lake Valley shows that the majority (96%) of the individuals categorized as having adult crania (age classes 4, 5, and 6) were in full adult pelage. "Adult" pelage does not necessarily correspond to reproductive maturity or fully fused sutures, as the juvenile pelage is replaced within the first several months of life (Howard and Childs 1959) and some individuals seem to be breeding before reaching full adult pelage. It does, however, represent a chronological stage that is, in this case, completed by the time the individual has reached adult stages of cranial development.

### Intrapopulation Variation

ANALYSIS OF AGE AND SEX EFFECTS. —Analyses of the Honey Lake sample suggest that variation among the three adult age classes of *Thomomys townsendii* is negligible, whereas

sexual dimorphism is pronounced. ANOVA results indicate that only TRL ( $P < .01$ ) and LAJ ( $P < .05$ ) show significant differentiation among age classes. The overall lack of appreciable age effect across the 32 characters indicates that there are only minor differences in the dimensions of the skull or body that correspond to suture fusion classes. However, there is significant ( $P < .01$ ) variation between the sexes for all but four of the characters examined: EH, IOC, HFM, and PMXT. Only TRL shows a significant ( $P < .05$ ) interaction effect between age and sex. It is important to note that the significant age effect found in TRL is dependent on the sex of the animal.

Due to the homogeneity among adult age classes, analyses of geographic character trends were performed without distinguishing among them. However, since the majority of the characters analyzed do indicate secondary sexual variation, the sexes were treated separately here as in other studies (Patton et al. 1979, Smith and Patton 1988). Adult male skulls can become larger and more heavily ridged than female skulls in instances of pronounced sexual dimorphism and can therefore introduce ontogenetic variation that could confuse the evaluation of adult skull morphology (Merriam 1895, Bailey 1915, Grinnell 1935). Since characters of the more uniform female skull are more reliable for phylogenetic interpretations, females have often been the focus of morphological descriptions (Grinnell 1931, 1935, Davis 1937). Discussion of the results of some analyses in this study will also emphasize females.

### Interpopulation Variation

ANALYSIS OF CRANIAL AND EXTERNAL CHARACTERS. —Univariate analyses of each of the 32 variables examined across the 31 localities reveal significant ( $P < .001$ ) levels of variation among populations for both males and females. Despite overall significance of variation in each of these characters, inspection of the means and ranges across the populations reveals general homogeneity and little sub-specific or regional cohesiveness. Based on the *F*-ratios of the variables, characters such as NL, CRD, PMXT, and LAJ suggest clearer population differentiation. The distinction between populations may be more apparent for these characters, but in some cases it reflects differentiation between populations of the

TABLE 1. Relative contributions of the first 11 discriminant functions of the analyses of 26 cranial characters.

DF	Females			Males		
	% variance	Cum. %	Eig. val.	% variance	Cum. %	Eig. val.
1	30.24	30.24	7.540	39.89	39.89	9.453
2	15.96	46.19	3.979	11.44	51.33	3.422
3	11.55	57.74	2.880	8.70	63.02	2.061
4	9.18	66.93	2.290	7.32	70.34	1.734
5	5.63	72.56	1.405	6.12	76.46	1.451
6	4.20	76.76	1.048	5.08	81.55	1.204
7	3.73	80.49	0.929	3.66	85.21	0.868
8	3.66	84.14	0.912	2.85	88.06	0.675
9	2.81	86.95	0.700	2.77	90.83	0.656
10	2.51	89.46	0.627	1.98	92.81	0.470
11	2.16	91.63	0.540	1.71	94.52	0.406

same currently recognized subspecies. NL values for populations of *Thomomys townsendii townsendii*, for example, encompass nearly the full range of values for the 30 female samples. In addition, subsets established by Duncan's multiple range tests indicate a large amount of overlap among the 31 samples, for all variables. In ranking the population means for each variable, no geographic trend is apparent; rather, a pattern of interdigitation of representatives from different geographic and subspecific units emerges. In instances where populations are ranked into nonoverlapping groups, populations of a given subspecies or geographic region are likely to be found in each group. For example, populations of *T. t. townsendii*, *T. t. elkoensis*, and *T. t. bachmani* are found in each of two nonoverlapping subsets that represent the highest and lowest values for CRD.

Discriminant function analysis was ultimately performed using 26 of the 28 cranial characters in order to maximize sample size. By removing LAJ and DPRO, characters that were often represented by missing values, the sample size increased with little effect on the ability to differentiate among the 31 populations. The discriminating power of the 26 cranial variables is comparable for the two sexes. Eigenvalues and percent variation for each discriminant function are given in Table 1. For females, the first 10 functions are needed before roughly 90% of the existing variance is used to distinguish between the populations. The first nine functions are necessary in the discrimination of males. Among females, the main contributing variables for DF1 are ONL, BAL, RL, NL, and CRD. Those for DF2 are RL, NL, RD, MAXM, and DJUG.

Ninety-six percent of specimens of each sex are correctly classified by the a posteriori probability of group membership of each specimen. Misclassified individuals are often placed in populations of another subspecies. While Snake River individuals are, with one exception, classified into other populations of that region, Humboldt River animals are sometimes placed in one of the Honey Lake Valley populations and vice versa.

The two-dimensional plots of individual scores show considerable interpopulation overlap in scores for DF1 and DF2 (see Figs. 4, 5). Despite this remarkably low amount of differentiation, discriminant function analyses succeed in revealing some patterns. Along DF1 Snake River populations form a more cohesive unit than that seen in the ANOVA results. A broad range in values is seen in the Humboldt River representatives. In fact, the range of coefficients found within *T. t. bachmani* alone (populations 1–9; see map, Fig. 2) nearly encompasses the DF1 values of the entire Humboldt River region. Some of the variation seen within *T. t. bachmani* is due to the deviation of populations 4 and 8 (Malheur Lake and Narrows region of Oregon) from the other samples of that subspecies (extreme southeastern Oregon, Quinn River, and Humboldt River areas). Also noteworthy is the similarity of Honey Lake Valley (*T. t. relictus*) populations in DF1 to the populations of southeastern Oregon and Nevada.

Individual scores show less obvious regional differentiation in DF2 than in DF1. The patterns seen for this function are subtle and involve within-subspecies differentiation; they are similar for both males and females. Nearly the full range of DF2 is found among

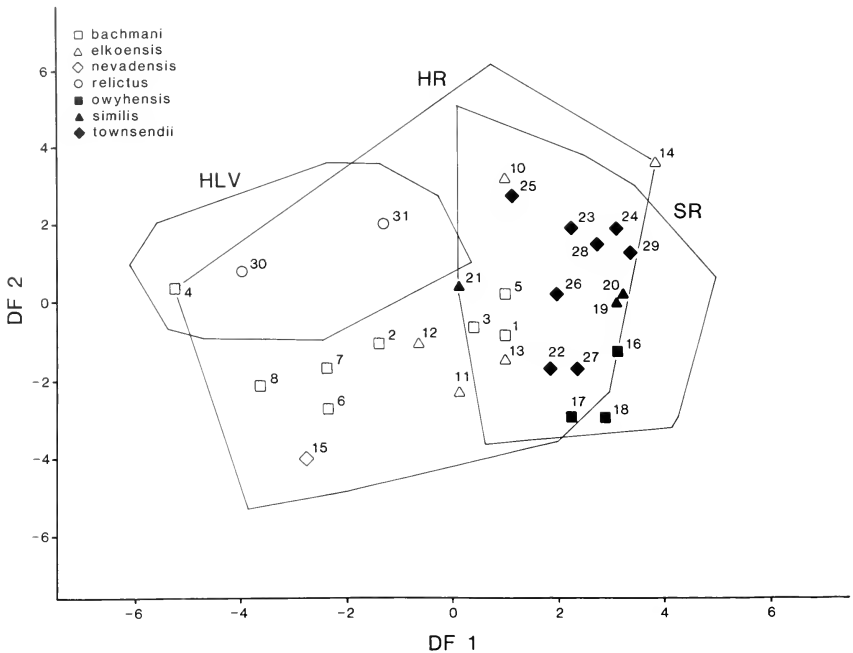


Fig. 4. Polygons encompassing individual scores for DF1 and DF2 for females from Honey Lake Valley (HLV), Humboldt River (HR), and Snake River (SR). Population centroids are indicated by numbered symbols. DF1 and DF2 represent 30.2% and 16.0% of the variance, respectively.

the Humboldt River animals. Honey Lake Valley animals fall into the same range as western *T. t. townsendii* populations (23–26, 28, 29) from along the Snake River. As seen in the ANOVA results, eastern populations (22 and 27) of *T. t. townsendii* are distinct from the majority of the samples of that subspecies. The easternmost populations of *T. t. elkoensis* (10 and 14) are also differentiated from the remainder of that subspecies. The significance of these deviations from subspecific and regional cohesiveness will be discussed later.

Matrices of *F*-ratios generated with the final steps of the discriminant function analyses were used to illustrate interrelationships of the 31 populations. A UPGMA phenogram summarizing these ratios was generated for each sex (Figs. 6, 7). The phenograms provide a summary of the contributions of all discriminant functions. The patterns mentioned above for DF1 and DF2 are apparent:

(1) subspecific and regional units are not readily distinguishable due to a large degree of overlap, (2) Snake River populations show a tendency toward cohesiveness, and (3) most intra-subspecific deviations in character trends are geographic subunits segregated in DF1 (populations 4 and 8 of *T. t. bachmani*) and DF2 (populations 22 and 27 of *T. t. townsendii*, populations 10 and 14 of *T. t. elkoensis*; see map, Fig. 2). In addition, populations of *T. t. relictus* and *T. t. nevadensis* and populations 4 and 8 of *T. t. bachmani* are well differentiated from the remaining groups based on *F*-ratios.

**ANALYSIS OF PELAGE COLORATION.**—The means and ranges of the three color variables for each locality are listed in Table 2. Discriminant function analyses of localities and locality groups show a substantial degree of overlap in coloration across the range of *Thomomys townsendii*. In the analysis of locality



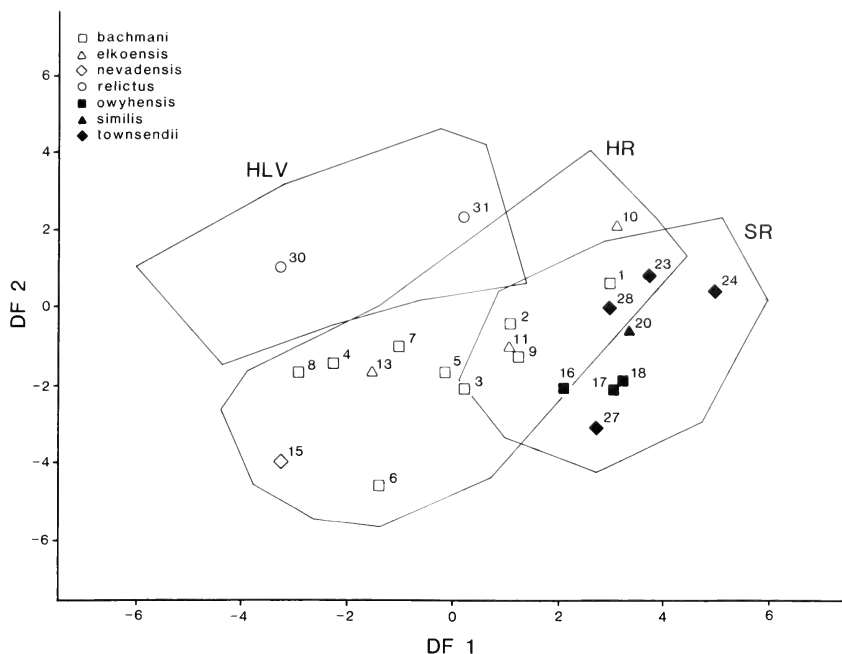


Fig. 5. Polygons encompassing individual scores for DF1 and DF2 for males from Honey Lake Valley (HLV), Humboldt River (HR), and Snake River (SR). Population centroids are indicated by numbered symbols. DF1 and DF2 represent 39.9% and 14.4% of the variance, respectively.

groups, only 29.69% of the cases were correctly classified using the three color variables as discriminators. The misclassified individuals were frequently placed into locality groups of other subspecies or into another major geographic region. Of the total variance, 73.97% is associated with the first discriminant function, which is most strongly represented by brightness. The contribution of brightness is similar in the discriminant function analyses at all levels.

The distribution of DF1 scores is graphically superimposed on the means and ranges for brightness in Figure 8, illustrating the concordance of the DF1 scores and brightness values and highlighting the contribution of brightness to DF1. Some separation along the function is apparent. For example, while populations of *T. t. elkoensis*, *T. t. similis*, and the eastern population (J) of *T. t. townsendii* are similar in ranges of DF1 values and group

means, they do not overlap with the values for *T. t. nevadensis*. However, there is a range of overlap along DF1, corresponding to a range of brightness values (10–15%), within which all locality groups are represented. If one were to characterize, in general terms, the pelage coloration at the subspecific level, *T. t. elkoensis*, *T. t. similis*, *T. t. owyhensis*, and most *T. t. townsendii* are relatively dark (locality means for brightness,  $\bar{x}$  = 9–11%); *T. t. bachmani*, *T. t. relictus* and some *T. t. townsendii* are brighter ( $\bar{x}$  = 11.5–14%); *T. t. nevadensis* is the brightest ( $\bar{x}$  = 17%).

If variation in pelage color is considered in the context of subspecific ranges or broader geographic units, there is a somewhat clearer pattern of differentiation from what is seen at the population level. Discriminant function analyses performed on localities grouped by subspecies or regions show increased discriminating power (percent correctly classified: 39.84 and 50.00, respectively).

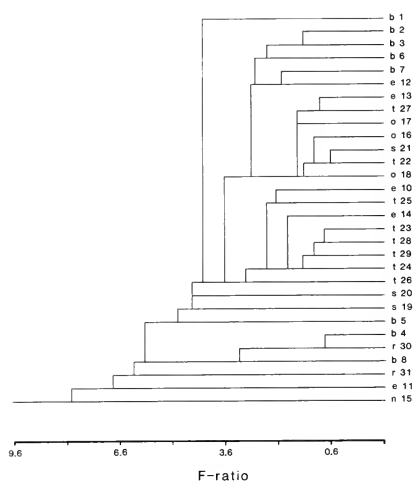


Fig. 6. UPGMA phenogram based on  $F$ -ratios from discriminant function analysis of females. Lowercase letters refer to subspecific designations and are followed by population numbers.

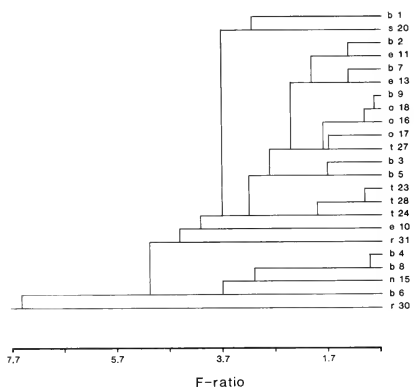


Fig. 7. UPGMA phenogram based on  $F$ -ratios from discriminant function analysis of males. Lowercase letters refer to subspecific designations and are followed by population numbers.

Analyses of variance confirm the relative importance of brightness in determining geographic trends in coloration. Of the color variables examined, brightness shows the most significant level of variation at every level of analysis. Amounts of between-group variation

for wavelength and purity become insignificant ( $P > .05$ ) when examined at the subspecific and/or regional levels. The homogeneous subsets of locality groups established by Duncan's multiple range tests (Fig. 9) again show *T. t. nevadensis* of central Nevada as clearly differentiated from all other populations. The other subsets encompass populations from different subspecies and from different geographic regions. When the subspecies are compared as units, *T. t. elkoensis*, from the eastern Humboldt River drainage, is grouped with *T. t. similis* from the Snake River. Comparison of the three geographic regions shows that animals from Honey Lake Valley and the Humboldt River are, in general, more similar in brightness values to each other than either is to the Snake River animals.

**COLOR VARIANTS.**—*Thomomys townsendii* occurs in a melanistic form as well as in the range of color morphs described above (Bailey 1915, Davis 1937). In addition, in this study one pure white individual was trapped at 6 mi. SE Murphy, Owyhee Co., Idaho. Melanic gophers formed a larger component of the specimens examined, being found in three of the seven subspecies with the following frequencies: *T. t. bachmani*, 8.25%; *T. t. relictus*, 0.57%; *T. t. townsendii*, 4.69%. In addition to these pelage morphs, a white "blaze" was frequently seen on the heads of individuals from two subspecies: *T. t. relictus*, 17.61%; *T. t. owyhensis*, 17.95%.

## DISCUSSION

The results of this study of *Thomomys townsendii* have shown general homogeneity in external, cranial, and pelage characters across a very broad and disjunct geographic range. Pocket gophers have long been noted for their adaptation to the soils they inhabit, especially in the differentiation of pelage coloration and body size (Grinnell 1927, Davis 1938, Ingles 1950). More recently, an emphasis has been placed on the role of the nutritional value of available food in determining body size (Smith and Patton 1980, 1988, Patton and Brylski 1987). The homogeneity seen in *T. townsendii* body size might be explained by the preference of this species for the deep lacustrine soils of the Great Basin. However, without further investigations it is difficult to

TABLE 2. Means and ranges for color variables brightness, wavelength, and purity.

Locality	<i>n</i>	Brightness	Wavelength	Purity
1	7	10.98 ( 7.26–14.28)	582.14 (580–583)	15.94 ( 5.98–24.95)
2	4	14.15 (11.30–17.04)	582.50 (582–583)	25.18 (20.62–27.69)
3	4	14.37 (11.96–17.20)	582.00 (581–583)	20.08 (16.70–22.39)
5	6	12.55 (10.38–14.22)	581.17 (580–582)	15.19 (10.10–17.26)
6	4	16.72 (15.41–17.72)	580.50 (580–581)	22.89 (21.71–24.03)
7	2	14.93 (12.93–16.92)	581.00 (581–581)	20.95 (19.36–22.55)
8	10	12.49 ( 9.91–14.66)	582.90 (582–584)	21.11 (15.94–27.37)
9	1	10.82 —	582.00 —	14.01 —
10	10	9.20 ( 7.02–11.31)	580.80 (578–582)	12.42 ( 3.33–26.69)
11	6	8.96 ( 7.69–10.96)	582.67 (582–584)	12.16 ( 6.61–16.87)
12	1	11.12 —	581.00 —	15.48 —
13	1	9.33 —	582.00 —	14.98 —
15	11	17.02 (14.15–20.19)	582.09 (581–584)	23.37 (18.84–27.80)
16	5	9.88 ( 8.66–12.44)	583.40 (583–584)	17.84 (15.31–24.20)
17	7	11.04 ( 9.42–14.26)	582.71 (581–584)	21.07 (16.15–29.24)
18	2	13.08 (12.29–13.87)	583.00 (583–583)	25.34 (20.18–30.50)
19	5	9.44 ( 7.24–10.88)	582.40 (581–584)	17.27 (10.63–20.83)
20	9	9.18 ( 6.83–10.75)	582.56 (580–586)	11.76 ( 5.31–18.76)
21	1	9.18 —	582.00 —	19.05 —
22	1	6.87 —	583.00 —	6.78 —
23	5	11.82 ( 9.85–14.16)	581.80 (581–583)	19.05 (14.67–25.62)
24	1	13.04 —	584.00 —	28.21 —
25	2	8.35 ( 7.83– 8.86)	581.50 (581–582)	19.90 (18.36–21.44)
27	3	9.94 ( 7.58–11.18)	583.33 (583–584)	21.23 (14.65–29.30)
28	5	11.43 (10.72–12.22)	582.20 (581–583)	15.85 (12.87–19.42)
30	5	13.73 (11.78–14.91)	581.20 (580–582)	19.03 (16.44–21.57)
31	10	13.76 (11.97–14.91)	582.20 (581–583)	20.30 (17.35–25.04)

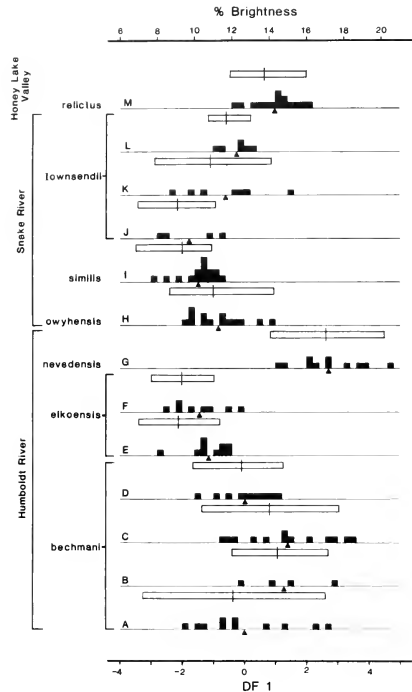


Fig. 8. Plot of individual scores for DF1 from color analysis and group ranges in % brightness values. Solid bars represent DF1 scores; triangles indicate group centroids. Open bars represent range in % brightness values; vertical lines indicate group means. DF1 represents 74.0% of the variance.

say whether the pattern seen is in response to color or other properties of the soil, quality of available food, isolation from other populations, or other influences. The pattern of morphological homogeneity seen in *T. townsendii* should be noted in contrast to the cranial differentiation demonstrated between subspecies or genetically defined intraspecific units in *Thomomys bottae* (Smith et al. 1983, Smith and Patton 1988) and in *Geomys bursarius* (Honeycutt and Schmidly 1979).

In 1937 Davis modified the status of the three subspecies of *Thomomys townsendii* recognized at the time. From his analysis of geographic variation in cranial and external morphology, he concluded that

Population Groups		Subspecies
<i>townsendii</i> J		<i>elkoensis</i>
<i>elkoensis</i> E		<i>similis</i>
<i>similis</i> I		<i>townsendii</i>
<i>elkoensis</i> F		<i>owyhensis</i>
<i>townsendii</i> K		<i>bachmani</i>
<i>owyhensis</i> H		<i>relictus</i>
<i>townsendii</i> L		<i>nevadensis</i>
<i>bachmani</i> A		
<i>bachmani</i> D		
<i>relictus</i> M		Geographic Region
<i>bachmani</i> C		Snake River
<i>bachmani</i> B		Humboldt River
<i>nevadensis</i> G		Honey Lake Valley

Fig. 9. Homogeneous subsets based on brightness. Vertical bars represent homogeneous subsets determined by Duncan's multiple range tests for each of the three color variables. Pairs of population group means were compared and placed in a subset if the means were not significantly different at the  $\alpha = .05$  level. Letters refer to population group designations.

7 distinct major centers of differentiation can be recognized, the population in each of which is fairly homogeneous and distinct from any other (Davis 1937:148).

Davis based his subspecific designations on the differentiation of characters or suites of characters across geography. In this study most of the same characters were analyzed; yet the results do not reveal consistent trends corresponding to subspecific units.

However, Davis (1937) also discussed variation within some of the subspecies he recognized. For example, within *T. t. bachmani*, animals from Quinn River and the Little Humboldt River differed from individuals taken along the Humboldt River between Lovelock and Battle Mountain. Davis noted that eastern populations of *T. t. townsendii* and *T. t. owyhensis* were "indistinguishable" externally and occupied similar soil types but that they were distinct in qualitative features of the cranium. Between subspecies two trends in cranial structure were apparent: *T. t. bachmani* was intermediate between

*T. t. relictus* and *T. t. nevadensis*, and *T. t. similis* was intermediate between *T. t. townsendii* and *T. t. elkoensis*.

Some of the analyses of the present study also suggest both variation within subspecies and similarities to other subspecies which, together, contribute to the homogeneity seen in *T. townsendii*. For instance, while populations of *T. t. bachmani* are very homogeneous in pelage characteristics, cranial analyses showed some differentiation among these samples, the northern populations (4 and 8) being the most divergent (DF1, also reflected in *F*-ratios). The eastern representatives of *T. t. townsendii* consistently deviate from the other populations of the subspecies. While these populations (22 and 27) are not especially distinctive on DF1 of the cranial analyses, they segregate from the other *T. t. townsendii* populations along DF2 and in the summary of the discriminant function analyses as shown by *F*-ratios. The color analysis represented them as the darkest of the Snake River populations and, again, segregated from the northwestern *T. t. townsendii* populations.

Cranial analyses also expose differentiation within *T. t. elkoensis* between the northeastern populations (10 and 14) and those to the south (11, 12, and 13). These populations are distinguished along DF2, the scores for populations 10 and 14 being very similar to those of the Snake River populations. Davis (1937) referred to the affinity between northeastern *T. t. elkoensis* and *T. t. similis* of the Snake River system in the context of the potential link between the two river systems. However, he called them "structurally" similar without detailing the characters involved. Pelage characters show *T. t. elkoensis* to be more cohesive as a subspecies, but they are the darkest of the Humboldt River populations and, again, more like the Snake River animals, possibly in response to some of the environmental factors discussed earlier. Because color analyses were not performed on soil samples in this study, an examination of any adaptive tendency for pelage to match background soil cannot be undertaken. However, Great Basin vegetation zones and the factors that determine these provide an interesting comparison.

The distribution of *Thomomys townsendii* occurs primarily in two of the vegetation

zones of the Intermountain Region as described by Cronquist et al. (1972). These are the Shadscale Zone and the Sagebrush Zone. Of these two plant communities, shadscale is more tolerant of saline soils and low moisture conditions. The distribution of shadscale communities in the northern Great Basin is nearly identical to the distribution of the *T. townsendii* populations that exhibit bright pelage. The distribution of the darker populations, including *T. t. elkoensis* and *T. t. similis* samples, falls in the Sagebrush Zone, which probably corresponds to less saline, moister, and therefore darker soils. It is also interesting to note that the eastern *T. t. townsendii* and some *T. t. owyhensis* samples were collected near one of the transitions between these two vegetation zones and therefore may also have come from darker soils.

Although the patterns seen in the morphological analyses are similar to some that Davis found, the characters on which these trends are based are not necessarily the same in both studies. For example, one of the variables contributing strongly to differentiation within *T. t. bachmani* in the discriminant function analysis is NL, but in Davis's study nasal length contributes to the cohesiveness of *T. t. bachmani* as a unit.

Of the areas of differentiation that Davis recognized, the one represented by *T. t. nevadensis* is the most consistently distinguished based on morphological criteria in this study. Although the pattern of overlap with other subspecies persists in the results of all analyses, the *T. t. nevadensis* sample at Austin is the most divergent in the discriminant function and color analyses.

Beyond differentiation into seven subspecies, Davis recognized other trends in *T. townsendii*. He divided *T. townsendii* into two groups based on the breadth of the dorsal surface of the premaxillae. The populations of the Snake River Plain comprised a narrow rostrum group, and those of Honey Lake Valley and the Humboldt River drainage had broader rostra. The present study has also shown differentiation between the two regions representing the Snake River and Humboldt River drainages. However, based on analyses of RW, PMXW, and PMXT, no segregation into broad and narrow rostrum groups is apparent. It is important to note the concordance between Davis's results and this

study in placing Honey Lake Valley populations within the Humboldt River region. Cranially, *T. t. relictus* is most similar to *T. t. nevadensis* and northern populations of *T. t. bachmani* along DF1 and in the *F*-ratio phenogram; they are not substantially differentiated from other Humboldt River animals along DF2. In color, they are also intermediate relative to Humboldt River populations.

Multivariate analyses of cranial characters provide the clearest differentiation between regions, showing some overlap but also considerable segregation along DF1, with the Snake River samples exhibiting a narrower range of DF1 values relative to the Humboldt River populations. None of the measurements relating to rostral width contributes importantly to DF1, although length-related characters do, including RL and NL. In the discriminant function analyses for cranial characters, most individuals were correctly classified into their respective populations. The placement of the misclassified individuals suggests similarities between the Honey Lake Valley and Humboldt River populations and greater differentiation of the Snake River populations. In contrast, the color analysis shows a good deal of overlap in pelage coloration of animals from the three regions. Individuals were classified into their respective subspecific units only 40% of the time when the classification was based on pelage characters, and the misclassified cases were often placed into another geographic region.

Animals from the Humboldt River drainage are more diverse morphologically than those of the Snake River populations. The Humboldt River DF1 values for the cranial analyses are broadly scattered along that axis. Brightness values for these populations range from among the darkest to the brightest known for the species. Although both regions include populations that are geographically well separated from one another, Snake River populations have somehow maintained greater morphological homogeneity. There could be a strong environmental component to this pattern in the form of quality of soil and food resources. In addition, the physiographic history and colonization of the two areas may have been sufficiently different to result in the varying degrees of regional differentiation seen today. These possibilities are considered further in a companion paper (Rogers 1991).

Fossil evidence suggests that in relatively recent times these pocket gophers may have been distributed along more of the Snake River basin than they are today. Fossil remains of *T. townsendii* and related forms are rare and known only from the northern part of the *townsendii* distribution (see Fig. 2). *Thomomys scudderi* and *Thomomys vetus* are both known from Wisconsin deposits at Fossil Lake, Oregon (Hay 1921, Davis 1937). Both taxa have been regarded as conspecific with *townsendii* or related to it. Elftman (1931) recognizes fossils from this area as *T. townsendii*. Davis (1937) considered *T. scudderi* more similar to *bottae* and felt *T. vetus* was a *townsendii* relative. Fossils assigned to *T. townsendii* have been found in Oregon at Fossil Lake (early-mid-Wisconsin; Elftman 1931, Allison 1966, Grayson 1982), in Idaho along the central and eastern Snake River Plain at American Falls (Sangamonian; Gazin 1935), Rainbow Beach (Wisconsin; McDonald and Anderson 1975), Wasden Site (Wisconsin to Recent; Guilday 1969), and Wilson Butte Cave (Wisconsin to Recent; Gruhn 1961). Three of these fossil records (Fossil Lake, Wilson Butte Cave, and Wasden Site) are outside the present range of *T. townsendii* (see maps, Figs. 1, 2). Due to the nature of the fossil materials (often only teeth or skull fragments), this evidence establishes, at best, that "townsendii-like" animals occurred during the late Pleistocene in the Snake River Plain and to the west at Fossil Lake, Oregon.

In summary, the results of this study do not lend support to the seven subspecific designations established by Davis (1937). There are differences among populations within current subspecies and similarities between populations of different subspecies in cranial and pelage analyses. These patterns suggest some validity in distinguishing between the populations of the two river drainage systems and some weakness in recognizing seven subspecific units. Within each river system more localized differentiation can be shown, such as the marked divergence of the Austin sample, but it is subtle and does not warrant taxonomic distinction at this point.

However, the results of these analyses deserve further consideration, as well. It has been demonstrated that approaches such as these frequently reflect the environmental component of the variation to be found

among populations, while historical influences and genetically based variants are left undefined. More detailed analyses of cranial shape would give a better indication of what evolutionary units exist in this species (Smith and Patton 1980, 1988, Patton and Brylski 1987, Patton and Smith 1989). In a companion paper (Rogers 1991) I investigate the electrophoretic and karyotypic aspects of variation in *Thomomys townsendii* to supplement the results of this morphological study with information that is likely to be more representative of historical events and more informative about the phylogenetic history of the species (Smith and Patton 1980). The results of morphological and genetic analyses are then considered in the context of the biogeographic history of the northern Great Basin to present more clearly patterns of evolutionary differentiation of *Thomomys townsendii*.

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## APPENDIX

### Specimens Examined

Listed below are specimens examined in the morphological and color analyses of this study. Boldface numbers preceding localities represent corresponding composite locality numbers. Each locality is followed by the sample size for the morphological analysis. Those specimens used in both the morphological and the color analyses are italicized, and specimens used only in the color analysis are italicized and marked with an asterisk (\*). Museum acronyms follow Yates et al. (1987).

#### *Thomomys townsendi nevadensis*

CALIFORNIA: Lassen Co., [30]. Amedee (2 females): MVZ 77591, 77592; 4 mi. ESE Amedee (1 female): MVZ 77593; Honey Lake, 6 mi. NW Amedee, 4000 ft. (1 female): MVZ 32990; 3.4 mi. N, 2.6 mi. W Doyle, 4250 ± ft. (1 male): MVZ 124165; 3.7 mi. NNW Doyle, 4200 ft. (1 male): MVZ 163624; 1.8 mi. S, 1.6 mi. W Herlong, 4060 ft. (2 males): MVZ 124168, 124169; Garnier Ranch, 2.4 mi. S, 1.5 mi. W Herlong, 4130 ft. (15 males, 11 females): MVZ 130120–130127, 130129, 130131–130134, 130137, 130138, 130140, 130141, 138411–138415, 149985, 149988, 149994, 149995; 2.8 mi. S, 0.2 mi. S Herlong, 4030 ft. (1 female): MVZ 130156; Honey Lake Valley, Garnier Ranch, 3 mi. SW Herlong (3 males, 3 females): MVZ 138429–138434; 0.3 mi. S, 3.0 mi. W Herlong, 4030 ft. (1 female): MVZ 124166; Bird Flat Ranch, 3 mi. S, 2.7 mi. W Herlong, 4080 ft. (18 males, 9 females): MVZ 163597, 163598, 163599, 163600, 163601, 163602, 163603, 163604, 163605, 163606, 163607–163623; 0.7 mi. S, 3.7 mi. W Herlong, 4020 ft. (1 male): MVZ 124167; 3.9 mi. W, 2.1 mi. S Herlong, 4030 ft. (6 males, 2 females): MVZ 130157–130164; Garnier Ranch, 5.0 mi. W, 1.5 mi. S Herlong, 4020 ft. (8 males, 5 females): MVZ 130143–130155; 5.1 mi. SW Herlong (by rd.) (4 males, 3 females): MVZ 149998, 150000, 150005, 150007, 150008, 150010, 150012; [31], 3.0 mi. S Johnstonville, 4440 ft. (1 female): MVZ 126029; Elysian Valley, 5.0 mi. S, 0.1 mi. E Johnstonville, 4360 ± ft. (1 male): MVZ 126027; Elysian Valley, 5.3 mi. S, 0.3



mi. E Johnstonville, 4330 ft. (1 female): MVZ 126028; 3.4 mi. W, 3.3 mi. N Litchfield, 4110 ft. (1 male, 2 females): MVZ 126030, 126031, 126033; 4.2 mi. N, 3.1 mi. E Litchfield, 4160 ft. (1 female): MVZ 126529; 3.4 mi. W, 4.3 mi. N, Litchfield, 4160 ft. (1 female): MVZ 126034; 3.5 mi. N and 3.2 mi. W Milford, 4070 ft. (2 females): MVZ 126389, 126390; 0.2 mi. N, 0.2 mi. W Peter Lassen Grave, 4340 ft. (1 male, 2 females): MVZ 129038–129040; 0.7 mi. N, 0.2 mi. E Peter Lassen Grave, 4280 ft. (1 male): MVZ 129041; 0.4 mi. E Standish (1 female): MVZ 122150; 2.4 mi. W Standish (1 female): MVZ 122151; Zangger Ranch, 3.8 mi. W Standish (1 male, 3 females): MVZ 122154–122158; 4 mi. W Standish, 4110 ft. (2 males, 11 females): MVZ 163625–163628, 163629, 163630, 163632, 163633, 163634, 163635, 163636, 163637, 163638, 5 mi. W Standish (1 male): MVZ 122153; 2 mi. S Susanville (1 male): MVZ 35271, 35273\*; 3 mi. S Susanville, 4200 ft. (3 males): MVZ 63341, 63342, 63343; 3.1 mi. S Susanville, 4200 ft. (1 male, 1 female): MVZ 129252, 129253; 4.5 mi. ENE Susanville, 4600 ft. (1 male, 2 females): MVZ 63335, 63337, 63338; 1.0 mi. N, 0.3 mi. W Wendel, 4060 ± ft. (1 male): MVZ 126035; 1.1 mi. N, 1.4 mi. W Wendel, 4030 ± ft. (1 male): MVZ 126036; 1.1 mi. N, 3.2 mi. W Wendel, 4010 ± ft. (1 female): MVZ 126037; Honey Lake Refuge, 4 mi. W Wendel, 4000 ft. (1 female): MVZ 114490.

NEVADA: Elko Co., [10], Elburz, 2 mi. W Halleck, 5200 ft. (1 male): MVZ 4442; 11 mi. NE Elko, 5200 ft. (2 males, 1 female): TCWC 36156, 36157\*, 36158, 36160; 4 mi. W Halleck, 5200 ft. (1 female): MVZ 67928, 0.5 mi. SW Ryndon, 5100 ft. (10 males, 10 females): MVZ 163508–163514, 163515, 163516–163518, 163519, 163520, 163521, 163522, 163523, 163524, 163525–163527, [14], 24 mi. SE Wells, Independence Valley, 5900 ft. (1 female): MVZ 135337; Eureka Co., [11], Evans (1 male, 1 female): MVZ 70583, 70584; Hay Ranch, 17 mi. SE Palisade, 5160 ft. (3 males, 15 females): MVZ 163528, 163529–163535, 163537, 163538, 163539–163541, 163542, 163543, 163544–163546; [12], 4 mi. S Romano, Diamond Valley (3 females): MVZ 70587, 70588, 70589, [13], Winzell (1 male, 1 female): MVZ 70585, 70586; Humboldt Co., [2], 1 mi. E Golconda, 4000 ft. (2 females) and 4100 ft. (1 male): MVZ 94733, 94735, 94736; 18 mi. NE Iron Point, 4600 ft. (2 males, 1 female): MVZ 67924, 67925, 67926; 1 mi. N Winnemucca, 4600 ft. (3 males, 1 female): MVZ 67929, 67930, 67932, 67933; [5], Big Creek Ranch, base of Pine Forest Mts., 4350 ft. (2 females): MVZ 7868, 7870; Quinn River Crossing, 4100 ft. (7 males, 12 females): MVZ 7854–7857, 7859, 7860, 7863, 7864, 7866, 7867, 163082, 163083, 163084, 163085, 163086, 163474, 163475, 163476, 163477; Jackson Creek Ranch, 17.5 mi. S and 5 mi. W Quinn River Crossing, 4000 ft. (1 male): MVZ 78655; [6], 6 mi. E Division Peak, 4200 ft. (2 males, 2 females): MVZ 95297, 95298, 95299, 95300; Flowing Sp., 7 mi. E and 3.5 mi. N Division Pk., 4200 ft. (1 male, 2 females): MVZ 95294, 95295, 95296; Lander Co., [15], Malloy Ranch, 5 mi. West of Austin, Reese River, 5500 ft. (12 males, 8 females): MVZ 37061, 37062, 37063–37065, 37066, 37067, 37068, 37069–37072, 37074–37078, 37079, 37080, 37082; 5.5 mi. W Austin, 5700 ft. (5 males, 11 females): MVZ 163549, 163550, 163551, 163552–163557, 163559, 163560, 163561, 163562, 163563, 163564, 163567; Pershing Co., [3], Lovelock, 3980 ft. (2 females): MVZ 64830, 64831; Big Meadow Ranch, Lovelock, 4000 ft. (3 males, 3 females): MVZ 163071\*, 163072, 163074, 163075, 163080, 163081,

163499; 3.3 mi. SW Lovelock (2 males, 2 females): MVZ 150014, 150016–150018; Tonlon, 3930 ft. (1 female): MVZ 67934, [1], 2 mi. NW Vahny, 4450 ft. (4 males, 17 females): MVZ 163478, 163479, 163480, 163481, 163482, 163483, 163484, 163485, 163486–163489, 163490, 163491, 163492, 163493, 163494, 163495, 163496–163498; [6], 11.5 mi. E and 22 mi. N Gerlach, 4200 ft. (1 male): MVZ 95301.

OREGON: Harney Co., [4], 4 mi. SW Narrows, 4200 ft. (4 males, 1 female): MVZ 163502, 163504–163507; [7], Lake Alvord, Alvord Desert (1 female): MVZ 44883; S end Lake Alvord, 4300 ft. (2 males, 2 females): MVZ 78649–78651, 78652; Borax Sprg., S end Lake Alvord, 4200 ft. (1 male): MVZ 78653; Alvord Valley, T37S, R33E, W 1/2 sec. 27 (1 male): PSM 20393; [8], 20 mi. S, 10.1 mi. W Burns, 4200 ft. (1 female): OSUFW 2960; 22.5 mi. S, 14.5 mi. E Burns (Malheur Refuge), (2 males, 3 females): OSUFW 1, 2, 3, 4, 5, 26 mi. S, 7 mi. E Burns, 4200 ft. (1 female): OSUFW 2961; 28 mi. S, 3 mi. W Burns, 4100 ft. (1 male): OSUFW 1646; Malheur Environmental Field Station, between N and S Coyote Butte (1 female): PSM 24427; 1 mile east of Malheur Refuge Headquarters (2 males): OSUFW 810, 1933; Narrows (5 mi. SW), 4000 ft. (2 males): MVZ 44885, 44886; Malheur Co., [9], 3 mi. N McDermitt, Nevada (1 male): PSM 6108.

#### *Thomomys townsendii townsendii*

IDAHOO: Bannock Co., [20], West Pocatello River bottom, Pocatello (1 male, 3 females): MVZ 46506, 46507, TCWC 494, 495; Pocatello Cr., 1 mi. NE Pocatello, 5000 ft. (3 males, 3 females): TCWC 33059\*, 33061, 33062, 33064–33067; 4 mi. NW Pocatello (4 males, 4 females): MVZ 46552, 46553–46556, 46558–46560; Floyd Johnson Ranch, 4 mi. NW Pocatello, 4500 ft. (6 males, 7 females): MVZ 163639, 163640, 163642–163645, 163648\*, 163650, 163651, 163652, 163653, 163654, 163655, 163656; Fort Hall Indian School, 10 mi. N Pocatello (1 male): MVZ 51904; Bingham Co., [20] 1 mi. E Pingree MVZ 72020\*, 72021\*; Canyon Co., [25], N side Snake River, 4 mi. S Wilder (1 male, 3 females): MVZ 72012, 72013, 72014, 72015; Elmore Co., [22], 3 mi. E Grandview, 2800 ft. (3 females): MVZ 163671, 163672, 163673; [27], Hammett (5 males, 4 females): MVZ 72003–72006, 72007, 72008, 72009, 72010, 72011; Owyhee Co., [16], 7.5 mi. SE Grandview, 2600 ft. (7 males, 16 females): MVZ 163568, 163569, 163570, 163571, 163572, 163573, 163574–163576, 163578, 163579, 163580–163589, 163591, 163592; [17], 5 mi. SE Murphy (2 males, 2 females): MVZ 67495, 67496–67498, 6 mi. SE Murphy, 3000 ft. (2 males, 1 female): MVZ 163593, 163595, 163596; Siaker Creek, 7 mi. SE Murphy (1 female): MVZ 67501; Castle Creek, 8 mi. S Oreana (2 males, 3 females): MVZ 67489, 67490, 67491, 67492, 67494; [18], 1 mi. SE Bruneau, 2600 ft. (1 male, 2 females): TCWC 33055, 33056, 33058; Indian Cove (2 females): MVZ 72001–72002; [26], S bank Snake River, Homedale (3 females): MVZ 71998–72000; Payette Co., [23], 1.5 mi. NE Payette, 2200 ft. (5 males, 1 female): MVZ 163677–163679, 163680, 163682, 163683; 2 mi. S Payette between Payette and Snake Rivers (3 females): MVZ 67502, 67505, 67506; 3 mi. E Payette (4 males, 3 females): TCWC 25929, 25930, 25931, 25933, 25934, 25935, 25936; Power Co., [19], 2.5 mi. NW American Falls, 4500 ft. (7 females): MVZ 163658, 163660, 163662, 163664, 163665, 163666, 163667; 4 mi. NW American Falls (1 female): MVZ 67507; [21], 2.5 mi. SW Michael,

4400 ft. (1 female): MVZ 51903; 5.5 mi. SW Michaud, 4400 ft. (1 female): MVZ 51902; Washington Co., [23], 2.9 mi. SE Weiser, 2100 ft. (1 male): MVZ 163687.

OREGON: Malheur Co., [29], Kane Springs (T21S, R43E, sec. 4) (2 females): PSM 20390, 20391; [24], W side Snake River, Ontario (2 males): MVZ 72017, 72018; 2.5 mi. N Ontario, 2100 ft. (2 males, 7 females): MVZ

163691, 163694–163696, 163701, 163702, 163704, 163706, 163707; [28], 1 mi. N, 5 mi. E Vale, 2500 ft. (1 male): OSUFW 3490; 2 mi. N Vale (1 female): PSM 19109; 3.5 mi. S Vale, 2270 ft. (6 males, 2 females): PSM 20382–20389; 5 mi. S, 2 mi. W Vale, 2300 ft. (1 male): OSUFW 2695; 6.5 mi. SSE Vale, 2799 ft. (1 male, 1 female): PSM 20380, 20381.

## EVOLUTIONARY DIFFERENTIATION WITHIN THE NORTHERN GREAT BASIN POCKET GOPHER, *THOMOMYS TOWNSENDII*. II. GENETIC VARIATION AND BIOGEOGRAPHIC CONSIDERATIONS

Mary Anne Rogers<sup>1</sup>

**ABSTRACT.**—Genetic variation across the known geographic range of *Thomomys townsendii* was examined by starch gel electrophoresis and nondifferentially stained karyotypes. All specimens examined had a diploid number of 76, but some populations possessed one pair of acrocentric chromosomes in an otherwise biarmed karyotype. Electrophoretic analyses of 16 populations revealed *Thomomys townsendii* to be among the least variable of pocket gopher species studied. Of 27 loci examined, 17 were monomorphic and heterozygosity values were low ( $H = .000-.028$ ,  $\bar{H} = .012$ ). Genic differentiation between populations was also low ( $S = .896-.998$ ,  $\bar{S} = .956$ ) and revealed little concordance with current subspecific units. The most marked differentiation is between the Honey Lake Valley/Humboldt River region and the Snake River drainage. Within each of these regions population variation is, in some cases, greater within than between currently defined subspecies. *F*-statistics show that the greatest genic differentiation is seen between populations, and a comparison of subspecies within a region shows the greatest homogeneity. The evolutionary history of *Thomomys townsendii* is discussed in the context of both the physiographic history of the region and the affinities of this species to *Thomomys bottae*. Results of this study and the patterns of differentiation found in the morphological analyses of the accompanying paper (Rogers 1991) indicate that the only consistent pattern to be discerned from the overall morphological and genetic homogeneity of *Thomomys townsendii* is that between populations of the Humboldt and Snake River drainage systems, which are here assigned to *Thomomys townsendii nevadensis* and *Thomomys townsendii townsendii*, respectively.

**Key words:** *Thomomys townsendii*, pocket gophers, genetic variation, evolutionary differentiation, geographic variation, electrophoresis, karyotype.

Since the revisions by Merriam (1895) and Bailey (1915), many studies have focused on defining and understanding morphological variation within the family Geomyidae. Aspects of fossoriality, such as specificity to soil type and low vagility, and environmental influences, such as climate, topography, and food resources, have long been considered in this context (Bailey 1915, Grinnell 1927, Davis 1937, 1940, Hall 1946, Ingles 1950). More recently, patterns of chromosomal and electrophoretic variation have been compared to and correlated with interrelationships among habitat preference, physiographic features, gene flow, and population size (Patton 1970, 1972, 1981, Nevo et al. 1974, Penney and Zimmerman 1976, Patton and Yang 1977, Honeycutt and Schmidly 1979, Tucker and Schmidly 1981, Sudman et al. 1987). To explain the patterns found, investigators have presented different arguments for a variety of evolutionary mechanisms. Patterns of genetic variation in pocket

gophers have been attributed to the selective forces associated with the homogeneous fossorial environment (Nevo et al. 1974, Penney and Zimmerman 1976) or to a series of stochastic processes and physiographic changes (Patton 1972, 1981, Patton and Yang 1977).

The geographic distribution and phylogenetic affinities of *Thomomys townsendii* make this species an interesting subject for genetic analyses. The presence of *T. townsendii* in the northern Great Basin is influenced by the distribution of deep fluvial and lacustrine soils and by the physical and biological barriers that interrupt and restrict these habitats. Patton and Smith (1981) examined allozymic and karyotypic relationships within the *bottae* group and determined *T. townsendii* to be derived from one of the geographic units of *T. bottae*. This genetic evidence and the morphological similarity found between these two species (Patton and Smith 1989) provide an evolutionary framework within which to interpret the patterns

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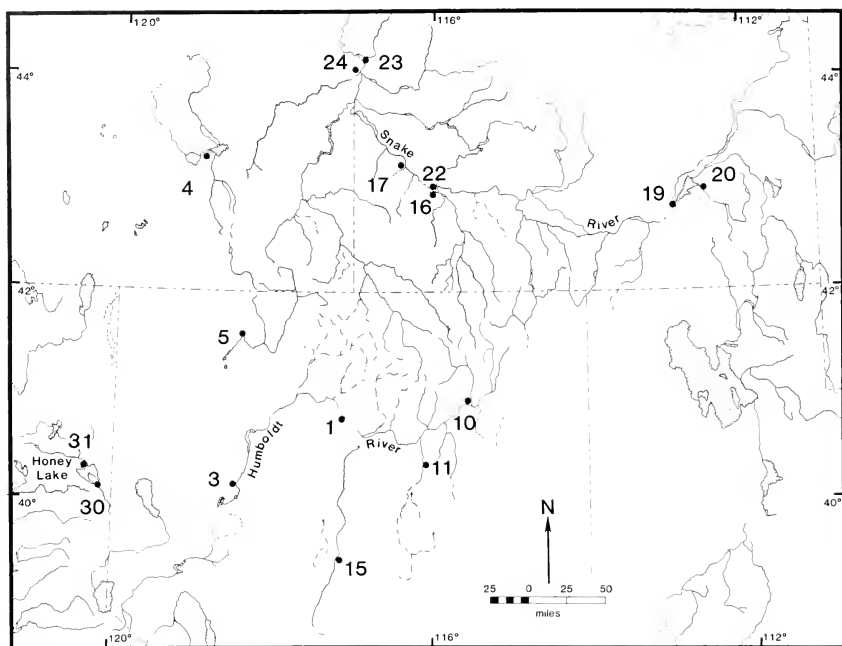


Fig. 1. Map of localities sampled for electrophoretic and karyotypic analyses. Locality information is given in the Appendix.

of allozymic and karyotypic variation of *T. townsendii*. Given the apparent phylogenetic affiliation, results of genetic analyses of *Thomomys bottae* synthesized by Patton (1981) are especially relevant to the present examination of genetic differentiation within *Thomomys townsendii*. In general, genic patterns in *T. bottae* do not reflect subspecific, topographic, or vegetational boundaries. Instead, broader geographic units are defined both karyotypically and genically. This pattern suggests that environmental factors often do not explain patterns of genetic variation, but historical biogeography and features of gopher populations such as vagility and effective population size may be influential.

The results of the genetic analyses of this study and the patterns of morphological variation discussed in the accompanying paper (Rogers 1991) will be considered in the context of the biogeographic history of the region and the phylogenetic affinities of this spe-

cies. These components of the biology of *Thomomys townsendii* make it possible to assess its evolutionary differentiation and the validity of current taxonomic designations of this species.

#### MATERIALS AND METHODS

##### Electrophoretic Procedures

During the spring and summer of 1981 and the spring of 1982, 252 gophers were collected using Macabee gopher traps. Sixteen populations from areas representing all seven recognized subspecies and the entire geographic range of *Thomomys townsendii* were sampled. The localities (numbered as in the accompanying morphological study [Rogers 1991]) and sample sizes are detailed in Figure 1 and in the Appendix.

These animals were preserved as skin and skull, skeleton only, or skull only specimens and are deposited in the Museum of

Vertebrate Zoology, University of California, Berkeley. Kidney, liver, and hemolysate and plasma blood fraction samples were prepared and then frozen in liquid nitrogen. Samples were later stored under ultra-cold conditions ( $-76^{\circ}\text{C}$ ) in the laboratory. Kidney and liver samples were homogenized in grinding buffer and centrifuged to produce extracts. Extracts and plasma samples were then analyzed by horizontal starch gel electrophoresis following procedures similar to Selander et al. (1971). The 27 loci scored and the tissue types used (K = kidney, L = liver, P = plasma) are as follows: *enzymatic proteins*: aconitase (E.C. 4.2.1.3, ACON; K), adenosine deaminase (E.C. 3.5.4.4, ADA; K),  $\alpha$ -glycerophosphate dehydrogenase (E.C. 1.1.1.8,  $\alpha$ GPD; K), alcohol dehydrogenase (E.C. 1.1.1.1, ADH-2; L), esterase (E.C. 3.1.1.1, EST-4; K), glucosephosphate isomerase (E.C. 5.3.1.9, GPI; K), glutamate-oxaloacetate transaminase (E.C. 2.6.1.1, GOT-1, GOT-2; K), glyceraldehyde phosphate dehydrogenase (E.C. 1.2.1.12, GAPDH; K), isocitrate dehydrogenase (E.C. 1.1.1.42, ICD-1, ICD-2; K), lactate dehydrogenase (E.C. 1.1.1.27, LDH-1, LDH-2; K), leucine aminopeptidase (E.C. 3.4.11 or 3.4.13, LAP; K), malate dehydrogenase (E.C. 1.1.1.37, MDH-1, MDH-2; K), mannose phosphate isomerase (E.C. 5.3.1.8, MPI; K), peptidase (leucyl-alanine substrate, E.C. 3.4.11 or 3.4.13, PEP-C; K), peptidase (leucyl-glycyl-glycine substrate, E.C. 3.4.11 or 3.4.13, PEP-B; K), phosphoglucomutase (E.C. 2.7.5.1, PGM-2; K), phosphogluconate dehydrogenase (E.C. 1.1.1.44, 6 PGD; K), purine nucleoside phosphorylase (E.C. 2.4.2.1, NP; K), sorbitol dehydrogenase (E.C. 1.1.1.14, SORDH; K), superoxide dismutase (E.C. 1.15.1.1, SOD; K); *nonenzymatic proteins*: albumin (ALB; K), prealbumin (PREALB; P), transferrin (TRF; P).

#### Karyotypic Procedures

Forty-one animals, representing all recognized subspecies of *Thomomys townsendii* (Appendix), were examined. Most were pretreated with yeast (Lee and Elder 1980, with modifications in dosage). Chromosome preparations were made from bone marrow cells as described by Patton (1967) except that KCl was used as the hypotonic solution. Air-dried slides were stained in Giemsa (10% stock stain solution in phosphate buffer) and

air-dried before mounting with coverslips. Determination of diploid numbers and construction of karyotypes followed standard procedures (Bender and Chu 1963, Patton 1967). Bi-armed chromosomes were categorized into either a metacentric/submetacentric class or a subtelocentric class after Patton and Dingman (1970), utilizing the arm ratio criteria of Patton (1967).

#### Statistical Analyses:

##### Electrophoretic Data

Alleles were designated alphabetically in order of increasing mobility, and genotype frequencies were analyzed using the BIOSYS-1 computer program (Swofford and Selander 1981). Analyses of geographic differentiation utilized Wright's (1978) *F*-statistics, and trees were constructed from coefficients of genetic similarity and genetic distance (Rogers' *S*, *D* [1972] and modified *D* [Wright 1978]) using UPGMA clustering and the distance Wagner method (Farris 1972).

## RESULTS

### Intrapopulation Variation

Seventeen of the 27 loci examined were monomorphic. All polymorphic loci are represented by dominant alleles with frequencies of 0.95 or less with the exception of GOT-1 (Table 1). This locus is fixed for alternate alleles in the populations of Honey Lake Valley and the Humboldt River drainage system versus those of the Snake River system. Using the 0.95 criterion of polymorphism, only EST-4 is polymorphic in more than 3 of the 16 populations studied.

Intrapopulation variation is also low across loci. Population averages for *H* (mean proportion of loci heterozygous per individual, direct count estimate), *P* (proportion of loci polymorphic, 0.95 criterion), and *A* (mean number of alleles per locus) are presented in Table 1. The mean number of alleles per locus per population ranges from 1.0 to 1.11, with a mean across populations of 1.07. The proportion of the loci that is polymorphic per population ranges from .000 to .111. Mean polymorphism, *P*, calculated across the *T. townsendii* populations studied, is .053. Heterozygosity values range from .000 in Murphy ( $n = 4$ ) and .002 in Pocatello ( $n = 19$ ) to .028 in Grandview-*t.* ( $n = 8$ ). The average





TABLE 2. Matrix of between-population genetic similarity using Rogers' S (1972).

Population	3	1	5	4	10	11	15	30	31	19	20	16	17	22	23	24
3 Lovelock	—															
1 Valmy	.971	—														
5 Quinn River	.971	.988	—													
4 Narrows	.949	.967	.966	—												
10 Ryndon	.959	.977	.976	.955	—											
11 Palisade	.965	.986	.985	.961	.973	—										
15 Austin	.938	.957	.955	.934	.960	.953	—									
30 Herlong	.962	.981	.979	.975	.968	.975	.948	—								
31 Standish	.972	.991	.989	.973	.977	.985	.958	.990	—							
19 Amer. Falls	.938	.958	.955	.933	.944	.953	.924	.948	.958	—						
20 Pocatello	.935	.956	.952	.930	.940	.956	.921	.945	.955	.997	—					
16 Grandview-o.	.929	.950	.946	.925	.935	.956	.915	.939	.949	.991	.994	—				
17 Murphy	.940	.957	.957	.935	.945	.951	.924	.949	.958	.998	.995	.989	—			
22 Grandview-t.	.935	.929	.929	.907	.918	.925	.896	.921	.930	.970	.967	.966	.972	—		
23 Payette	.924	.945	.941	.920	.930	.949	.910	.934	.944	.986	.989	.988	.985	.957	—	
24 Ontario	.933	.953	.950	.929	.942	.952	.921	.943	.953	.995	.994	.988	.994	.966	.987	—
	3	1	5	4	10	11	15	30	31	19	20	16	17	22	23	24

TABLE 3. Rogers' S (1972) coefficient of similarity averaged by subspecies and by region.

Subspecies	# pops.	1	2	3	4	5	6	7
1 <i>bachmani</i>	4	.969						
2 <i>elkoensis</i>	2	.970	.973					
3 <i>nevadensis</i>	1	.946	.956	****				
4 <i>relictus</i>	2	.978	.976	.953	.990			
5 <i>similis</i>	2	.945	.948	.923	.952	.997		
6 <i>owghensis</i>	2	.942	.947	.920	.949	.995	.989	
7 <i>townsendii</i>	3	.933	.936	.909	.938	.984	.982	.970
Region	# pops.	1	2	3				
1 Humboldt River	7	.964						
2 Honey Lake	2	.974	.990					
3 Snake River	7	.937	.945	.984				

\*\*\*\*Only one population included.

heterozygosity was calculated across the 12 populations of  $n \geq 10$ . The value for  $\bar{H}$  was not altered ( $\bar{H} = .012$ ).

#### Interpopulation Differentiation: Electrophoretic Analysis

The populations of *T. townsendii* examined were arranged within four hierarchical levels: local population, subspecies, region, and species. The geographic regions (and corresponding subspecies) included the following: the Humboldt River drainage system (*T. t. bachmani*, *T. t. elkoensis*, *T. t. nevadensis*), Honey Lake Valley (*T. t. relictus*), and the Snake River drainage system (*T. t. owghensis*, *T. t. similis*, *T. t. townsendii*). Tables 2 and 3 represent the matrices of genetic similarity based

on Rogers' S (1972) for the 16 populations, 7 subspecies, and 3 regions examined.

The range in similarity values for the populations of *T. townsendii* is .896 to .998, with  $\bar{S} = .956$ . Examination of the subspecific and regional treatments of these data reveals some discordance between subspecific or regional affinity and degree of genetic similarity. For example, in Tables 2 and 3 some populations of *T. t. bachmani* exhibit, on average, more genetic similarity to *T. t. elkoensis* and *T. t. relictus* than to other members of their own subspecies. These results are similarly displayed in the regional comparison where some populations of the Humboldt River region show a higher average similarity to Honey Lake than to some of the other populations within the Humboldt River system.



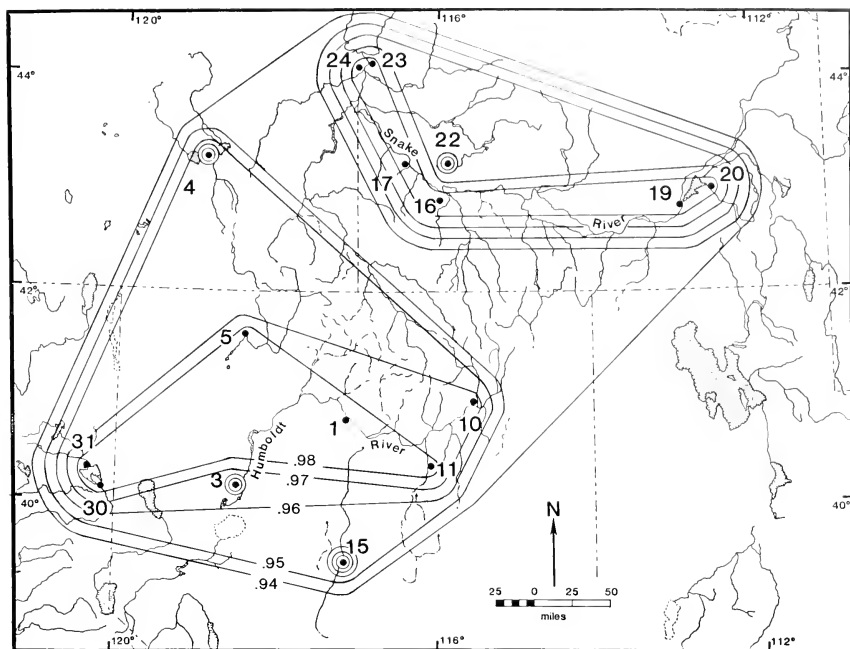


Fig. 2. Contour diagram derived from UPGMA phenogram based on Rogers' (1972) coefficient of similarity,  $S$ . Intervals represent a Rogers'  $S$  of .01. Goodness-of-fit statistics for phenogram are as follows: Farris (1972)  $F = 0.977$ , Prager and Wilson (1976)  $F = 0.852$ , percent standard deviation of Fitch and Margoliash (1967) = 1.187, cophenetic correlation coefficient = 0.882.

The Snake River subspecies are, however, on average most similar to the other subspecies of that region.

The unweighted pair group method of analysis was employed to cluster these data and illustrate these same trends in interpopulation similarities. Figure 2 presents the results of this analysis in the form of a contour diagram. Beyond general homogeneity among the *T. townsendii* populations ( $S = .939$ ), the most obvious feature of the contour diagram is the separation of the Honey Lake Valley and Humboldt River populations from the Snake River populations, forming two major clusters ( $S > .95$ ). This dichotomy is concordant with subspecific designations and hydrographic relationships. Within each cluster, however, similarity values do not correspond to current taxonomy or geographic affinities. For instance, within the Humboldt

River/Honey Lake cluster, the populations of geographically peripheral *T. t. relictus* (Standish and Herlong) show affinities to some of the populations of the Humboldt River subspecies. The Standish population from Honey Lake Valley and the Valmy population from north central Nevada are the most similar pair of that major cluster and are therefore more similar to each other than either is to any other representative of its own subspecies. The *T. t. nevadensis* sample from Austin is the most divergent population from the Humboldt River region. Within the Snake River cluster, the greatest genic similarity values are also found between geographically well-separated populations. Grandview-*t.*, a *T. t. townsendii* population situated centrally in the Snake River distribution, is the most differentiated population of that cluster.

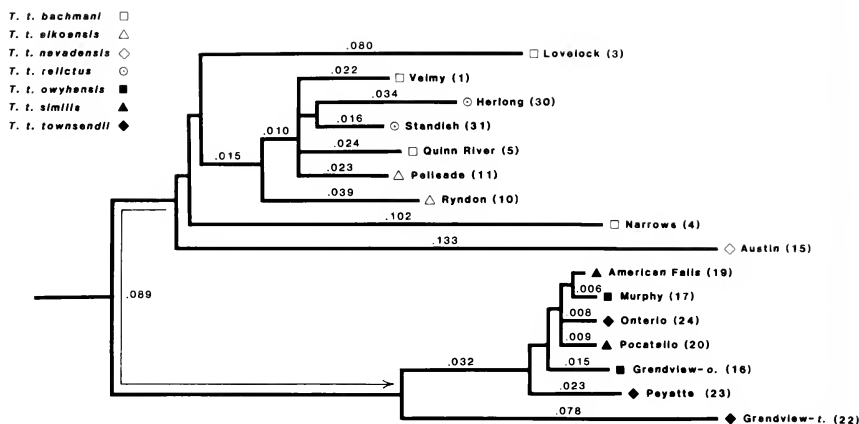


Fig. 3. Wagner tree based on Wright's (1978) modification of Rogers' *D*. Tree is rooted at midpoint and was constructed using Swofford's (1981) optimization algorithm. Goodness-of-fit statistics for tree are as follows: Farris (1972)  $F = 0.631$ , Prager and Wilson (1976)  $F = 3.255$ , percent standard deviation of Fitch and Margolias (1967) = 9.358, cophenetic correlation coefficient = 0.995.

Figure 3 provides a phylogenetic tree produced by the distance Wagner procedure of Farris (1972) based on Wright's (1978) modification of Rogers' *D*. Additional trees, constructed with and without the use of Swofford's (1981) optimization algorithm and using Rogers' *D* (1972), give the same general topology. The most notable difference among these trees is in the position of the divergent populations within the Humboldt River cluster. Trees generated using Rogers' *D* (1972) show these populations arising from within different small clusters (all separated from adjacent clusters by branch lengths less than .01), in contrast to their peripheral position in trees generated with the modified Rogers' *D* (Wright 1978). Of the four trees generated, the one presented in Figure 3 was chosen for its high correlation coefficient (range in cophenetic correlation coefficients = .986-.995).

Several features are shared by the contour diagram derived from the UPGMA phenogram and all four Wagner trees. The most notable is the existence of two major clusters that separate the populations into the two river drainage systems. Divergent populations within each of these clusters are consistently well differentiated in all the algorithm/coefficient combinations utilized. These pop-

ulations are Austin, Narrows, Lovelock, and Grandview-*t*. Each main cluster consists of a group of populations that cluster at a relatively high level of similarity and whose identity as a group is maintained in all analyses. Beyond the basic dichotomy between the two major river systems, there is no apparent concordance between geographic distance or hydrographic relationship and genic similarity.

The *F*-statistics of Wright (1978) were calculated to assess how genetic differentiation is partitioned within and between the hierarchical levels established in this study. As mentioned above, the 16 populations sampled correspond to the lowest level of the hierarchy, with subspecies, regions, and the total as higher levels. The variance components and  $F_{ST}$  values estimating the amount of variation accounted for by each of the subdivisions relative to another are given in Table 4. These were calculated for the polymorphic loci only. The greatest amount of differentiation is seen in comparing all the populations sampled ( $F_{ST} = .672$ ). Of the comparisons made, subspecies compared within a region are the least differentiated ( $F_{ST} = .151$ ). Within the total, interpopulation comparisons show greater differentiation than those between subspecies; these in turn show greater genic divergence than do comparisons between regions.

TABLE 4. Variance components and  $F$ -statistics (Wright 1978) combined across polymorphic loci.

Three geographic regions used in hierarchical classification (Humboldt River, Honey Lake Valley, Snake River)		
Comparison	Variance component	$F_{ST}$
Population-subspecies	.252	.392
Population-region	.366	.484
Population-total	.798	.672
Subspecies-region	.114	.151
Subspecies-total	.547	.460
Region-total	.433	.364
Two geographic regions used in hierarchical classification (Humboldt River/Honey Lake Valley and Snake River)		
Comparison	Variance component	$F_{ST}$
Population-subspecies	.252	.392
Population-region	.342	.468
Population-total	.798	.672
Subspecies-region	.091	.124
Subspecies-total	.574	.460
Region-total	.456	.384

Similarly, within a region, interpopulation differentiation is greater than that measured between subspecies. Averaged across all loci, the  $F_{ST}$  calculated for all populations is .130.

The same statistics were calculated for a classification scheme with two regions, Honey Lake Valley populations being included with those of the Humboldt River drainage (Table 4). This set of  $F$ -statistics shows decreased differentiation between the populational and subspecific units within a region and greater differentiation between regions compared to the results of the three-region scheme. Honey Lake Valley populations fit relatively homogeneously into the Humboldt River region. The overall pattern still suggests that the greatest extent of differentiation is between the smallest subdivisions and that there is relative homogeneity between the subspecies of a region.

The total limiting variance or total gene diversity ( $HT$  of Nei 1973, 1977) per locus was calculated for each of the 10 polymorphic loci. GOT-1 exhibits the highest level of diversity, reflecting the fixed difference between the Humboldt/Honey Lake region and the Snake River region ( $HT = .492$ ). This locus is probably responsible for most of the homogeneity (low  $F_{ST}$ ) found among subspecies within a region. Four polymorphic loci have moderate

$HT$  values (.120-.147) while the five remaining polymorphic loci are low (.012-.049). Locus-by-locus chi square tests for heterogeneity between populations were also calculated. Those loci that exhibit the most significant levels of heterogeneity (GOT-1, PGM-1, ADH-2, and PREALB) are, for the most part, the same loci that create the greatest differentiation between the various hierarchical levels in the  $F$ -statistic analysis. These loci also contribute to the level of differentiation seen in the four divergent populations, Austin, Narrows, Lovelock, and Grandview- $t$ .

#### Interpopulation Variation: Karyotypic Analysis

All individuals karyotyped showed a diploid number of 76. Five of the seven subspecies (*T. t. elkoensis*, *T. t. nevadensis*, *T. t. owyhensis*, *T. t. similis*, and *T. t. townsendii*) are represented by 16 pairs of meta- or submetacentric chromosomes ranging in size from large to small, and 21 pairs of large to small subtelocentric chromosomes (fundamental number [FN] = 148). In contrast, *T. t. bachmani* and *T. t. relictus* are characterized by 16 pairs of meta- or submetacentrics, 20 pairs of subtelocentrics, and a single medium-sized acrocentric pair (FN = 146). All seven subspecies have a large submetacentric X chromosome and a minute acrocentric (dot) Y chromosome.

#### PHYSIOGRAPHIC HISTORY OF THE NORTHERN GREAT BASIN

The Great Basin extends from the Sierra Nevada and Cascade Range in the west to the Wasatch Range and Colorado Plateau in the east. The northern and southern limits are defined by the Columbia and Colorado plateaus and the Mojave and Sonoran deserts. The Great Basin has internal drainage and is made up of over 150 smaller basins, separated by more than 160 north-south-oriented mountain ranges (Morrison 1965). Many of the rivers, lakes, and playas of these basins are remnants of the Pleistocene lakes Bonneville and Lahontan.

The climate of the Great Basin is semiarid to arid. Mean annual precipitation varies from year to year and increases with elevation. Precipitation may range from 10 cm in the basins

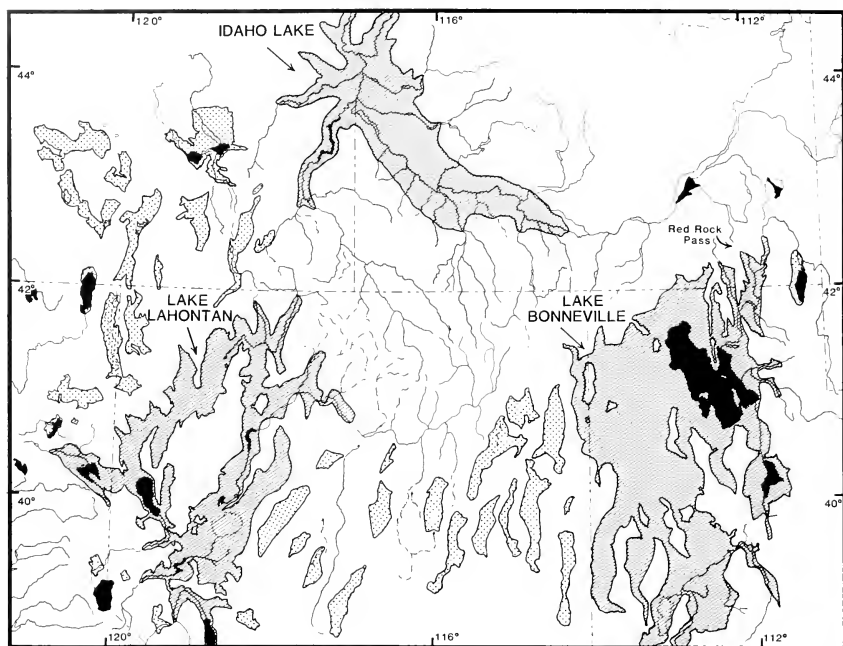


Fig. 4. Map of late Pliocene and Pleistocene lakes of the northern Great Basin (after Morrison 1965 and Wheeler and Cook 1954). The limits of Idaho Lake, Lake Lahontan, and Lake Bonneville are indicated by diagonal shading. Idaho Lake is of late Pliocene/early Pleistocene age. Lakes Lahontan and Bonneville and smaller lakes (stippled) are of Pleistocene age. Present-day lakes are represented by solid black areas. Point of overflow of Lake Bonneville at Red Rock Pass is indicated by arrow.

to over 76 cm in some of the higher mountains. Average January temperatures range from 25 F (−4 C) at Burns, Oregon, to 44.5 F (7 C) at Las Vegas, Nevada. Average July temperatures range from 67 F (19 C) at Burns to 86 F (30 F) at Las Vegas (Morrison 1965). As there are no drainages from the basin, precipitation is lost only to evaporation and transpiration. Evaporation increases and precipitation decreases in a southward trend. This latitudinal trend, coupled with the effect of elevation on temperature and evaporation, influences hydrographic features of the present-day Great Basin, as well as the existence and size of Pleistocene lakes (Meinzer 1922, Mifflin and Wheat 1979).

#### Pleistocene Lake Lahontan

The Great Basin of the Quaternary was divided, as today, into many hydrographic

basins, the two largest of which were Lake Lahontan and Lake Bonneville (Fig. 4). Only the features of Lake Lahontan will be emphasized here, as the area covered by this drainage is closely reflected by the range of *Thomomys townsendii* in the northern Great Basin. Details of the features of Lakes Lahontan and Bonneville can be found in the monographs of Russell (1885) and Gilbert (1890). Broecker and Kaufman (1965), Morrison (1965), and Benson (1978) provide more recent discussions of the history of these basins.

The present-day Lahontan drainage includes parts of eastern California, southeastern Oregon, and much of northern Nevada. To the west and south it includes the Eagle Lake, Honey Lake, Lake Tahoe, and Walker Lake systems. The Reese and Humboldt rivers drain into Lahontan Basin from the east and south while the Quinn River makes

up the northern component. The boundaries of the lake, at its highest level during the Wisconsin, encompassed the following drainage basins: Honey Lake, Pyramid Lake, Winnemucca Lake, Carson Lake, Walker Lake, Smoke Creek Desert, Black Rock Desert, part of the Truckee River, Humboldt River (eastward to a point near Golconda), and Quinn River (Russell 1885, Benson 1978).

The climate of the Wisconsin was characterized by great fluctuations in temperature and precipitation. Cool, wet times (pluvials), synchronous with the glacial intervals, resulted in high water levels in the Great Basin lakes. Each lacustrine maximum was followed by warmer, drier periods during which the lakes subsided. A variety of interpretations exists for the extent and timing of the fluctuation of the level of Lake Lahontan (Broecker and Kaufman 1965, Morrison 1965, Benson 1978). Benson (1978) suggests that besides the most recent pluvial episode (spanning roughly 25,000 to 9,000 years before present [YBP]) Lake Lahontan reached at least one other high stage before 40,000 YBP. He found no evidence for high lake levels between 40,000 and 25,000 YBP but recognized two subsequent to that time: 25,000–21,500 YBP and 13,600–11,000 YBP. The intervening period represented lower lake levels, but most basins remained connected during this time.

Subsequent to the second deep-lake period, the climate of the Great Basin began a warming and drying trend (Antevs 1948). From 9000 to 5000 YBP the Lahontan Basin was warm and arid, with all lakes except Pyramid Lake desiccated. In the last 5000 years water levels rose in Pyramid and Walker lakes until they were tapped for agricultural use during the past 100 years (Benson 1978).

The pre-Wisconsin history of the Great Basin is not as well documented as that of Lake Lahontan time. Since lakes of the early and mid-Quaternary probably occupied regions that lakes Lahontan and Bonneville occupied subsequently, the majority of these deposits have been buried by younger ones. Exposed deposits, however, suggest two pre-Wisconsin lacustrine intervals correlated with the Kansan and Illinoian glaciations. Early deposits from outside the areas inundated by Lake Lahontan have been found in the following regions: along the middle Reese River, Pine Valley, Smith Valley, and Carson Valley (Morrison 1965).

### Snake River Plain

While the Snake River Plain is hydrographically not part of the Great Basin, it is a natural component in terms of fauna, flora, and climate (Davis 1939, Cronquist et al. 1972). As much of the northern part of the distribution of *T. townsendii* lies within this area, the physiographic history of the Snake River is pertinent to this study.

The Snake River Plain has been shaped by a long history of lava flows. The geography of the eastern plain is more dominated by remnants of volcanic activity than is the west. These eastern lavas are, in general, younger (late Pleistocene to Recent) than those of the western basin. Kuntz et al. (1986) suggest a minimum age range of 15,000–2,000 YBP for some of these formations. Pleistocene lavas forced the Snake River into its present course along the east plain and formed the surface of the plain there (Malde 1965).

The topographically diverse western plain is cut by more tributaries and canyons of the Snake River and is covered with lacustrine and fluvial deposits. Some of the western lacustrine deposits can perhaps be explained by the former route of the Snake River and the establishment of Idaho Lake (Fig. 4). Wheeler and Cook (1954) suggest a possible late Pliocene route to the Pacific, running from western Idaho to southern Oregon via the Owyhee River. The route continues south-westward along the Steens, Pueblo, and Pine Forest mountains, across Black Rock and Smoke Creek deserts of Nevada to Honey Lake Valley. From here it moves to Chilcoat Pass and westward to the Feather River. In the late Pliocene/early Pleistocene the waters of the Snake were impounded and Idaho Lake formed in western Idaho and eastern Oregon. In early Pleistocene times Idaho Lake found an outlet, and the Snake River began its northward course into the Columbia drainage. Alternatively, Taylor (1960) suggests that the early route of the Snake River may have emptied into the Pacific via the Klamath River rather than the Feather River.

Another hydrographic link within the northern Great Basin is seen in the incidence of overflow of Lake Bonneville into the Snake River Plain. The Bonneville basin experienced a Wisconsin pluvial history similar to that described for Lake Lahontan. During one of the deep-lake periods, Lake Bonneville

overflowed at Red Rock Pass (SE of Pocatello, Idaho; Fig. 4) into a tributary of the Snake River (Morrison 1965). Malde (1968) discusses the details of the catastrophic flood and the confusion over the age of the event. It is here regarded as late Wisconsin, about 12,000 YBP (Broecker and Kaufman 1965, Morrison 1965). The flood path extended across the Snake River Plain and parts of the bed of ancient Idaho Lake to a point only several miles from the Oregon border. The duration of major flood effects is estimated at a few days, although discharge continued for at least a year.

#### HISTORICAL BIOGEOGRAPHY OF *THOMOMYS TOWNSENDII*

Today *Thomomys townsendii* is found in fluvial and lacustrine soils of southern Oregon and Idaho, northern Nevada, and north-eastern California (Rogers 1991: Fig. 1). At the western edge of its distribution, *townsendii* is found in the Honey Lake Valley. To the northeast the species inhabits the Quinn River drainage system, Black Rock Desert, Alvord Desert, and the basin of Harney and Malheur lakes. Gophers follow the Humboldt River from Lovelock to the vicinity of Wells, Nevada. They are distributed along the Little Humboldt River and other tributaries to the north of the Humboldt. To the south they are found along the Reese River, in Pine and Huntington Creek valleys, Independence Valley, and Diamond Valley. Along the Snake River Plain they inhabit the vicinity of American Falls Reservoir and, to the west, the stretch of the Snake River and its tributaries from Hammett, Idaho, to the vicinity of Vale, Oregon.

The physiographic history of the northern Great Basin explains many aspects of the current distribution of *Thomomys townsendii*. The Great Basin in the Miocene and Pliocene was characterized by moderate topographic relief and a trend toward warming climates. By the end of the Pliocene there were widespread grasslands and well-developed lacustrine and riparian environments (Axelrod 1950). As discussed previously, southern Oregon and Idaho had a history of lava flows. The Pleistocene topography of the Great Basin was in part characterized by lakes and rivers that formed a network of intercon-

nected drainage basins as their water levels rose and fell with climatic fluctuations. Remnants of these Pliocene and Pleistocene hydrographic features are the deep and moist lacustrine and fluvial soils of the type that *Thomomys townsendii* inhabits today. It was not until post-Wisconsin times that desert conditions prevailed in the Great Basin to the extent that some of these soils became uninhabitable.

The disjunct nature of the current distribution of *Thomomys townsendii* reflects the boundaries of these historical drainage basins and gaps in the distribution of the preferred soil type of the species (Rogers 1991: Fig. 1). A major division in the current distribution of *townsendii*, and one that is reflected in both genetic and morphological analyses of this and the companion study (Rogers 1991), lies between populations of the Snake River and Humboldt River drainages. These two regions of the *townsendii* distribution persist primarily on the remnants of historical Lake Idaho and Lake Lahontan drainage basins (Fig. 4). Today they are well isolated from each other by mountain ranges and scrub desert. Suitable habitat for *townsendii* was clearly once more abundant and continuous than it is today.

It is useful here to discuss historical events and hydrographic features relevant to establishing where suitable habitat once existed for *Thomomys townsendii*, including where the populations of the Snake River and Humboldt River may have once been connected. A historical network of drainage basins extended from Malheur Lake and the Owyhee River, south through Honey Lake Valley and Lake Lahontan, and east to the limits of the Bonneville basin. Remnants of Idaho Lake (late Pliocene/early Pleistocene) can also be included here as a potential continuation of lacustrine deposits extending from southwestern Oregon into southern Idaho (Fig. 4). Davis (1937) discusses the possibility of an eastern hydrographic link leading from the Humboldt River and Pleistocene Lake Lahontan into the Snake River drainage via the historical overflow at Red Rock Pass mentioned earlier. While this information will be useful in interpreting the general history of this species, both chronologically and geographically, the geological data for the area under consideration are sufficiently limited

that the correlation of specific historical events with specific patterns found in *Thomomys townsendii* cannot be undertaken. A review of the distributions of other Great Basin organisms will be used to help reconstruct the historically suitable habitats and dispersal routes for *Thomomys townsendii*.

Evidence from fossil and Recent freshwater fish and invertebrate distributions not only substantiates the existence of hydrographically related connections through the Great Basin, but also suggests possible corridors through which *T. townsendii* could have colonized the northern part of its present range. In his study of the fish of the Lahontan basin, Snyder (1918) found that some fish species are most closely allied to the fauna of the southeastern Oregon lakes. He found potential affinities with the Bonneville basin also. Miller (1958) similarly discusses affinities between the Lahontan and Bonneville basins based on their respective fish faunas and notes that there may have been a historical connection between the basins in the Pliocene or early Pleistocene. Miller found the fauna of the upper Snake River to be sufficiently similar to the Bonneville basin to be included in the Bonneville system.

Taylor (1960) presented distributional information for fossil and Recent freshwater clams and snails that suggests a historical network of lakes and streams leading from the Snake River through southern Oregon and northeastern California into the western Great Basin. His evidence does not suggest a Lahontan-Bonneville link. The investigation by Bisson and Bond (1971) into the origin of the fish of Harney Basin in southeastern Oregon also supports the suggestion of a dispersal corridor from the Snake River to southeastern Oregon. An ancient connection between Harney Basin and Malheur River provided a route for fish dispersal and explains the faunal affinities seen today. Stream connections were obstructed, in part, by a late Pleistocene lava flow, damming the water of Harney Basin.

A detailed analysis of fish distributions and drainage basins of the intermountain region, including the Great Basin, is presented by Smith (1978). His data on the distributions of 83 fish species suggest a well-linked Klamath (southern Oregon)-Snake-Bonneville group and a separate group representing the Lahon-

tan Basin. Analyses of the strengths of the barriers of 48 drainage basins suggest the following: (1) the Bonneville-upper Snake barrier is not a strong one, as evidenced by the Bonneville flood, (2) a Harney Basin-Snake River connection is suggested, (3) with the above two exceptions, colonization between the Snake River Basin and the Great Basin is rare, and (4) the Lahontan Basin shows low internal barrier strength, but the barrier between Lahontan and Bonneville is substantial.

While *T. townsendii* is not dependent on aquatic habitats, it exhibits a clear preference for lacustrine soils. The importance of the fish and mollusk evidence lies in describing a network of intermittently connected aquatic habitats in an area that has since been replaced by, or bisected by, lava flows and desert. These faunal studies and the brief geographic histories presented suggest potential links via Pleistocene hydrographic features on both the eastern and western ends of the current *townsendii* distribution. Details of the type of stream-to-stream network that must have existed to make gopher dispersal through southeastern Oregon possible are presented by Bisson and Bond (1971). Whether the route was as far east as Harney Basin or further west, through northeastern California, as suggested by Taylor's (1960) data, remains unclear. However, such a western hydrographic network appears to be a more viable corridor for pocket gopher dispersal than does the eastern Lahontan-Bonneville-Snake connection described for Great Basin fishes by Miller (1958). In fact, *Thomomys townsendii* is not known from the Lake Bonneville region, and, as outlined in the companion paper (Rogers 1991), there is no fossil evidence to suggest that this was ever part of the species range.

Morphological evidence presented by Davis (1937) suggests affinities between Pocatello (*T. t. similis*) and northeastern Nevada (*T. t. elkoensis*) animals and therefore an eastern link between northern and southern populations. To explain the apparent similarity, he proposed that the gophers followed the northern Bonneville shores into Idaho during the flood at Red Rock Pass (late Wisconsin). This study gives no clear indication of which route may have been taken. Only the color analysis shows any obvious similarity between

populations of the two river systems, again between *T. t. elkoensis* and *T. t. similis* populations (Rogers 1991). However, it has been demonstrated that pelage data should be treated carefully in interpreting the historical patterns of pocket gophers. Studies of *T. bottae* (Patton et al. 1979, Smith and Patton 1980, Smith et al. 1983) have clearly shown the environmental influence on variation in pocket gopher coloration. In fact, the correspondence between pelage color and vegetation zone suggests that dark soils may be a factor these two subspecies have in common (Rogers 1991).

A further suggestion that Red Rock Pass did not serve as a dispersal corridor for *T. townsendii* is presented by Wells's (1983) discussion of montane conifer dispersal in the Great Basin. Red Rock Pass is one of the two topographically high connections between the high central plateau of the Great Basin and the western Rocky Mountains. The 1820-meter contour that Wells uses to outline these high mountain connections is graphically complementary to the distribution of *T. townsendii* and delineates historical and present-day boundaries to eastward dispersal.

#### DISCUSSION

Causes of genic homogeneity in fossorial rodents have been of particular interest to some authors. Nevo and Shaw (1972) and Nevo et al. (1974) have applied a model for selection for homozygosity in uniform subterranean environments to data for *Spalax ehrenbergi* and *Thomomys talpoides*, which both show very low levels of genic variation within and among populations. Other authors have found this selection model inappropriate for explaining the genetic patterns seen in *Thomomys*, arguing that features of pocket gopher population biology and stochastic factors explain their genetic divergence (Patton and Yang 1977, Patton 1981, Patton and Feder 1981). In contrast to the pattern of genic homogeneity seen in *talpoides*, variation within and among populations of *bottae* is high. Small, effective population size, non-random breeding, and migration rate in conjunction with historical changes in habitat, distribution, and population connectedness are cited as variables that have affected the genetic patterns of *T. bottae* and its relatives

(Patton 1981). Results of this study are also consistent with the expected effects of these kinds of historical and population factors.

#### Patterns of Genetic Variation in *Thomomys townsendii*

The results of genic and karyotypic analyses of *Thomomys townsendii* reveal a pattern of extreme genetic homogeneity across a very broad and disjunct geographic range. The parameters of intrapopulation variation presented in this study categorize *townsendii* as being one of the least variable of the pocket gopher species studied. This species shows less variability (63% monomorphic) than other members of the *bottae*-group or *Thomomys* in general (*T. bottae*: 9% monomorphic, Patton and Yang 1977; *T. umbrinus*: 17%, Hafner et al. 1987; *T. talpoides*: 29%, Nevo et al. 1974).

*Thomomys townsendii* is also low in heterozygosity values and in average proportion of polymorphic loci relative to other rodents and to mammals in general (mean  $H = .039$  for 50 mammal species examined, Avise and Aquadro 1982; also, see reviews by Selander et al. 1974, Powell 1975, Nevo 1978, Kilpatrick 1981). While the ranges in population values for  $P$  and  $H$  in *T. townsendii* overlap with those values in other gopher species, the means across populations in this species are among the lowest known in pocket gophers ( $\bar{P} = .053$  and  $\bar{H} = .012$ ). The means and ranges of values for closely related species are  $\bar{P} = .334$  (.130-.565) and  $\bar{H} = .093$  (.030-.169) for *Thomomys bottae* (Patton and Yang 1977) and  $\bar{P} = .183$  (.043-.391) and  $\bar{H} = .051$  (.008-.100) for *Thomomys umbrinus* (Hafner et al. 1987). Of the pocket gopher species exhibiting lower levels of within-population variability (Selander et al. 1974, Honeycutt and Williams 1982, Hafner and Barkley 1984), none maintains these low levels so uniformly over such a broad geographic range as does *Thomomys townsendii*.

Analyses of genic variation have also shown a high level of similarity ( $\bar{S} = .956$ ) among the populations of *townsendii*. While these values are not unique among rodent studies (Avise 1974), they are extreme among *Thomomys* species (*T. bottae*:  $\bar{S} = .81$ , Patton and Yang 1977; *T. umbrinus*:  $\bar{S} = .80$ , Patton and Feder 1978, and Hafner et al. 1987; *T. talpoides*:  $\bar{S} = .84$ , Nevo et al. 1974). Whereas values in *townsendii* are high in comparison to *bottae*



as a whole, comparable levels of similarity are seen among the Great Basin populations of *bottae* (Patton and Yang 1977).

The nature of allozymic variation between populations in this species reflects the effects of rare variants at a small number of those loci examined. Wright's  $F$ -statistics show that populations are the units of greatest differentiation (highest  $F_{ST}$ ) of any of the hierarchical levels compared. Within a geographic region, populations are more differentiated than are the subspecies of that region. However, all populations are united at a high level of genic similarity,  $S = .939$ .  $F_{ST}$  values for *Thomomys bottae* (Patton and Yang 1977) similarly show interpopulation differentiation representing a large component of the variation. This was true throughout the populations sampled in this study and within each of the geographic areas. Variation within this group of pocket gophers is generally greatest between the local units of any given area. The subspecific or regional categories within these species are thus internally quite heterogeneous.

The distinction between the two geographic regions is the only clear division at any level in *T. townsendii* and is due mostly to the effect of the single locus GOT-1, which is fixed for alternate alleles in populations of the Humboldt River/Honey Lake Valley versus the Snake River. The divergent populations within each of the regions are differentiated slightly from the remainder of their respective clusters by shifts in allele frequencies or by possession of an allele not found elsewhere. These few variants are of little absolute significance in distinguishing these populations from the remainder of their cluster, however. Patton and Feder (1981) showed in studies of *Thomomys bottae* at Hastings Reservation that genic differentiation between fields can be as high as the differentiation found between subspecies of a region in *T. townsendii* (*T. bottae*  $F_{ST} = .142$ , *T. townsendii*  $F_{ST} = .151$  and  $.124$ ). Considered in this context, the genic differentiation represented among the populations and subspecies within the two geographic units is remarkably low.

Results of the karyotypic analysis corroborate the findings of Wentworth and Sutton (1969) and Thaeler (1973) that the diploid number is 76 in all *Thomomys townsendii* subspecies. The only differentiation found within the otherwise totally biarmed karyo-

type is the presence of a single acrocentric pair of chromosomes in samples of *T. t. bachmani* and *T. t. relictus*. This pattern differs from the karyotypes reported by Wentworth and Sutton (1969) and Thaeler (1973), who group the chromosomes of all seven subspecies in the following way: 12 pairs of metacentrics, 22 pairs of submetacentrics, and 3 pairs of acrocentrics ( $FN = 142$ ); the X chromosome is a large submetacentric, and the Y is a small acro- or subtelocentric. The lack of agreement with the published results can be explained, in part, by the lack of resolution in standard karyotypes. Without the aid of banded material, one is forced to use an arbitrary morphological classification. This may explain the disagreement in the numbers of chromosome pairs in each of the biarmed categories.

Although the distinction between unarmed and biarmed chromosomes is more easily made, Wentworth and Sutton (1969) and Thaeler (1973) assigned three pairs of chromosomes to the unarmed group, while one or none was so assigned in this study. The classification of the single unarmed pair in *T. t. bachmani* and *T. t. relictus* remains somewhat ambiguous. However, the existence of such a variant in an otherwise karyotypically homogeneous species is almost to be expected. Variation seen in related species is often of this nature; arm number may be polymorphic or polytypic, while the diploid number remains constant within a given taxon (Patton 1972, Patton and Feder 1978, Patton and Sherwood 1982, Hafner et al. 1987). In addition, it is significant that the alternative karyotype is found in the Honey Lake Valley and in the neighboring *T. t. bachmani* populations which together form the western component of the Humboldt River region. Since southeastern Oregon samples of *T. t. bachmani* were not karyotyped in this study, it cannot be determined whether this pattern extends to those populations as well.

The discrepancy found in the morphology of the Y chromosome is less easily explained as preparation artifact. The Y chromosomes presented by Wentworth and Sutton (1969) are substantially larger than the dot chromosomes found in this study. As all other *bottae*-group karyotypes exhibit the minute acrocentric morphology in the Y chromosome (Patton and Dingman 1970, Patton 1972, Patton and Feder 1978, Hafner et al. 1987), it is probable

that *Thomomys townsendii* also shows this pattern.

The amount of genic variation found in geomyids is often accompanied by greater karyotypic differentiation than that seen in *Thomomys townsendii* as well. Average similarity values within *Geomys bursarius* and *G. personatus* (data of Y. J. Kim presented by Nevo et al. 1974 and Selander et al. 1974) are .76 and .86, respectively, and both species are karyotypically polymorphic. Of the specimens analyzed allozymically by Kim (Selander et al. 1974), *G. bursarius* was represented by seven chromosomal forms ( $2n = 70, 72, 74$  and  $FN = 68-74$ ), and *G. personatus* was represented by five ( $2n = 68, 70$  and  $FN = 68-74$ ). Chromosomal variation in these species is due to Robertsonian changes (centric fusions and fissions), inversions, and translocations. Examination of contact zones in other studies of *G. bursarius* has shown that barriers to genetic exchange exist between some chromosomal forms (Honeycutt and Schmidly 1979, Tucker and Schmidly 1981, Bohlin and Zimmerman 1982). Within the *Thomomys talpoides* complex (Nevo et al. 1974), average genic similarity for the six karyotypic variants examined is .874. Thaeler believes that these morphs represent at least five separate species (Nevo et al. 1974). Within this complex diploid numbers range from 40 to 60, and chromosomal changes are typically due to Robertsonian changes and pericentric inversions.

Patton and Yang (1977) discussed differences in genetic variability of *T. bottae* and members of the *T. talpoides* complex. The pattern seen in *talpoides* is one of genic homogeneity and chromosomal differentiation to the point of reproductive isolation. Historical fragmentation and isolation of populations, bottlenecks, and founder effects may have resulted in the fixation of chromosomal rearrangements and fixation for alternate alleles where loci were once polymorphic. It is suggested that if reproductive isolation were attained, genic homogeneity would be maintained in these isolates. In contrast, chromosomal variability of *T. bottae* does not seem to affect reproductive isolation and interpopulation genic variability and within-population heterozygosities are high. Extensive range fragmentation is not suggested for *bottae*, gene flow is believed to have been less inter-

rupted, and therefore genetic variability has been maintained. Historically, isolated populations of *bottae* were not chromosomally differentiated to the point of being reproductively isolated from other populations. Therefore, recontact with populations could have meant interbreeding, and bottlenecks that occurred due to isolation could have been overcome.

#### Evolutionary and Biogeographic History of *Thomomys townsendii*

While *Thomomys townsendii* does not share the genetic diversity characteristic of the *bottae*-group, its distributional history is more similar to that of *bottae*, undisturbed by glaciation, than to *talpoides*, whose boreal distribution was sculpted by glacial influences. Furthermore, the genic pattern in *townsendii* is remarkably similar to the kind of variation seen in the Great Basin populations of *bottae* (Patton and Yang 1977). The concordance between genic patterns of these two species in the same geographic area suggests that a similar history of biogeographic and stochastic events may have influenced their evolution in the Great Basin.

Given that historical biogeography may have affected the genetic patterns of *bottae* and *talpoides*, it is useful to understand the evolutionary history and affinities of *T. townsendii* before trying to interpret the patterns seen in this species. Studies by Bailey (1915), Thaeler (1980), and Patton and Smith (1981) support a dichotomy within *Thomomys*. Morphological, electromorphic, and karyological analyses place *Thomomys townsendii* in the *bottae*-group, which also contains *T. bottae*, *T. umbrinus*, and *T. bulbivorus*. This group, characterized as the "heavy-rostrum" group by Bailey (1915), can be distinguished karyotypically as having diploid numbers ranging from 74 to 88 (Thaeler 1980, Patton and Sherwood 1982). These characters distinguish the *bottae*-group from *T. talpoides* and other members of Bailey's (1915) "slender-rostrum" group (with diploid numbers ranging from 40 to 60 [Thaeler 1980]), including *T. clusius*, *T. idahoensis*, *T. mazama*, and *T. monticola*. Thaeler (1980) formalized this dichotomy by recognizing the slender- and heavy-rostrum groups as separate subgenera, *Thomomys* and *Megascapheus*, respectively. Patton and Smith (1981) did an electrophoretic analysis of

six *Thomomys* species (*talpoides* and *monticola* in addition to the *bottae*-group species) and treated *T. townsendii* as part of the *bottae* unit; all alleles found in *townsendii* were also found in *bottae*. The same study determined that *bottae* and *townsendii* were a sister-group relative to *umbrinus*, that *townsendii* stemmed from within one of the major geographic units of *T. bottae*, and therefore that *bottae* was paraphyletic relative to *townsendii*. An analysis of cranial shape also supports this relationship (Patton and Smith 1989).

The evolutionary relationships of *bottae*, *townsendii*, and *umbrinus* are manifested in comparisons of karyotypic morphology and cellular DNA content, and in hybrid zone studies. The whole-arm heterochromatin found in *townsendii* resembles the pattern seen in *bottae* and is distinct from the interstitial heterochromatin characteristic of *umbrinus* (Patton and Sherwood 1982). Similarly, the amount of cellular DNA (C-value) found in *townsendii* is within the range found in *bottae* populations, whereas *umbrinus* has a higher C-value than would be expected for *T. bottae* with a similar karyotype (Sherwood and Patton 1982).

The karyotypic similarity between *bottae* and *townsendii* can be contrasted to the meiotically problematic structural rearrangements found between *bottae* and *umbrinus* (Patton 1973, Patton 1981), although studies of hybrid zones indicate that genetic introgression does not occur in either case. Both *townsendii* and *umbrinus* are known to hybridize minimally with *bottae* (12% and 11–15% hybrids, respectively). In *bottae-umbrinus* hybrids, F1 males are sterile, female fertility is reduced, and there is no genetic introgression (Patton 1973). While some F1 individuals from crosses of *bottae* and *townsendii* show normal reproductive characteristics, there is again no evidence for genic or morphological introgression into the parental populations (Patton et al. 1984). Both pairs of hybridizing species remain genetically isolated species, but only the *bottae-umbrinus* case is likely to be chromosomally mediated. The lack of genetic introgression in the presence of karyotypic similarity between *bottae* and *townsendii* suggests other influences. The significance of behavior in this case has been suggested (Patton et al. 1984).

The evolutionary affinities between *townsendii* and *bottae* are further reflected in information from studies of the distribution of gopher lice. Pocket gopher species often serve as hosts to more than one species of louse, and a single louse species may be found on more than one species of pocket gopher (Emerson and Price 1981). *T. townsendii* is known to be the host of one louse species, *Geomydoecus idahoensis*, except in two zones of hybridization with *bottae* (Patton et al. 1984). In Honey Lake Valley *T. townsendii relictus* hybridizes with *T. bottae saxatilis* and *T. bottae canus*. In these hybrid zones the *bottae* louse is found on some of the "pure" *townsendii* as well as on some of the hybrids. *G. idahoensis* belongs to the *oregonus* species group. Another member of this group, *Geomydoecus shastensis*, is morphologically very similar to *idahoensis* and, interestingly, is the louse found on *T. bottae saxatilis* (Price and Hellenthal 1980).

The level of chromosomal and genic similarity of *townsendii* and *bottae* and the evidence for paraphyly (Patton and Smith 1981, 1989) suggest that *Thomomys townsendii* was derived from *Thomomys bottae*. In addition, Bailey (1915) and Davis (1937) recognized the morphological affinities between the two species. Further examination of the nature of this morphological similarity demonstrates that there is basically no difference in cranial shape between the two species. It has been suggested that the difference in body size between the two species may have resulted in differences in demographic features that eventually created genetic isolation (Patton and Smith 1989).

What can be determined from the results of this study regarding the nature of the distribution of this species from the time of its founding population to the present? Was the range of *townsendii* once continuous over the northern Great Basin and subsequently fragmented by unsuitable habitats? Or is the distribution of *townsendii* the result of relatively recent dispersal from one segment of the species range?

The concordance of genetic data with historical and biogeographic patterns has been emphasized in other pocket gopher studies. Patton (1981) discusses the influences of history and features of pocket gopher population biology in the context of the agreement of karyotypic and genic data for *Thomomys*

*bottae*. Morphological patterns of differentiation, however, are often best explained by environmental factors such as quality and color of the soil and nutritional value of available food and probably do not provide much information regarding the evolutionary history of *T. bottae* (Smith and Patton 1980). Further studies (Patton and Brylski 1987, Smith and Patton 1988) have demonstrated that while pelage coloration and body size are strongly influenced by environmental factors, cranial shape variation is more likely to represent genetically based changes. In the absence of an analysis focusing on cranial shape in *Thomomys townsendii*, the results of the genetic analyses will be emphasized in developing a historical scenario for this species.

While the nature of the historical distribution of *Thomomys townsendii* is not easily determined by the results of this study and its companion paper (Rogers 1991), evidence does exist that eliminates some possibilities and suggests others. A description of the historical biogeography of the northern Great Basin that focuses on the changes in and the availability of suitable habitat for *Thomomys townsendii* has been presented. It indicates that the wetter climates of the Pleistocene of the northern Great Basin produced a network of lacustrine and fluvial soils that were occasionally continuous until desert conditions prevailed, rendering some of these soils uninhabitable. The continuity of these habitats could have provided historical corridors for dispersal.

However, while these historical connections can be reconstructed, it is unlikely that the species could have maintained a continuous range over most of the northern Great Basin at one time. Rather, it seems feasible that after the origin from *T. bottae*, segments of the range of *T. townsendii* were connected to various degrees at different points in its distributional history. Barriers to the continuity of the range probably arose at different times in different places. As climates increased in aridity and lakes receded, some areas became unable to support gopher populations, and *townsendii* remained along rivers and receding lake shores. Further fragmentation and isolation of some sections of the range of *T. townsendii* probably occurred with the intrusion of lava flows. Information from this study supports the idea that a fragmented

distribution has always been characteristic of this species and also suggests in which areas a more continuous distribution may have existed historically.

For instance, analyses of the genetic data indicate that populations of the Snake River belong to a very cohesive cluster ( $\bar{S} = .984$ ) despite the geographical separation of the *T. t. similis* populations by more than 100 miles. Fossil evidence from Wilson Butte Cave (Gruhn 1961, Rogers 1991) suggests that continuity between the western (*T. t. owyhensis* and *T. t. townsendii*) and eastern (*T. t. similis*) parts of the Snake River distribution may have existed fairly recently. Only the eastern *T. t. townsendii* population (22) is clearly differentiated from the other Snake River populations. Most of the samples from this region differ from each other in allele frequencies and, in one case, in the presence of a rare ADA allele in low frequency. The magnitude of the differentiation of the Grandview *T. t. townsendii* population (22) is primarily due to the appearance of the PGM *c* allele in relatively high frequency (.625). This allele was not encountered in other populations. The reason for the divergence of this population is not clear, but geologic evidence suggests that historically this area may have been isolated by lava flows (Malde and Powers 1962, Malde 1965).

While variation in the Humboldt River region is very limited, more genetic differentiation is seen among these populations than among those of the Snake River region. The only karyotypic differentiation documented in this study is seen in representatives of two of the Humboldt River subspecies. Analyses of the populations of this region resulted in a cluster of six genetically very similar ( $\bar{S} > .97$ ) populations and three more differentiated populations: Lovelock, Narrows, and Austin. The members of the more cohesive cluster include *T. t. elkoensis*, two of the four *T. t. bachmani* populations, and the Honey Lake Valley (*T. t. relictus*) populations. These samples are differentiated from one another by the presence of one to four alleles in low frequency that are not found in other populations of that cluster.

Despite their peripheral location, Honey Lake Valley populations display affinities to the Humboldt River populations as they did in the morphological analyses of the

companion paper (Rogers 1991). Examination of the *F*-statistics further supports the inclusion of Honey Lake Valley populations in the Humboldt River geographic region. Subunits within regions show less differentiation when Honey Lake Valley is regarded as a part of the Humboldt River region. Greater genic similarity is found between Honey Lake Valley populations and certain Humboldt River populations than among some Humboldt River populations. The same is true at the subspecific level. Historically, Honey Lake Valley was part of Lake Lahontan, so the affinity to these populations is not surprising. Only the karyotypic analysis shows Honey Lake Valley populations deviating from most other populations in that *T. t. relictus* and *T. t. bachmani* possess a single acrocentric pair among an otherwise biarmed complement of chromosomes.

The genic divergence of two of the *T. t. bachmani* populations (Lovelock and Narrows) is due to the prevalence of a single allele not found elsewhere. The *T. t. nevadensis* sample from Austin is the most differentiated population of the Humboldt River region. The magnitude of this divergence is attributable almost entirely to a fixed difference for a PREALB allele. This allele is otherwise only present, in moderately low frequency (.200), in a single *T. t. elkoensis* population. Austin and Narrows animals are consistently differentiated from the other populations in both genetic and morphological analyses (Rogers 1991). This may reflect their peripheral position relative to the Lahontan drainage system. Although located in a Pleistocene lake basin, Narrows is actually outside the Lahontan hydrographic basin, but it was probably once connected to the main basin. The divergence of this population from other units of this region probably reflects its isolation due to a combination of encroaching desert regions and the influence of the drainage divide.

Austin is located in the Reese River valley, south of the Humboldt River. The Reese River was a tributary of the Humboldt River during Lahontan times but was not represented by a pluvial lake (Morrison 1965), suggesting relative aridity in this basin even during pluvial times. Today the Reese River reaches the Humboldt only intermittently so that habitable areas for *T. townsendii* may be restricted to the southern portions of

this valley. Isolation by inadequate habitat may have contributed to separation and divergence of this population. Furthermore, *T. talpoides* is currently found in this valley only 24 miles north of Austin. The presence of this species may have subsequently enforced existing physical barriers.

Another possible explanation for the differentiation exists if this area was one of the earliest colonized subsequent to the derivation of *townsendii* from *bottae*. Davis (1937) remarked that, of the *townsendii* subspecies, *T. t. nevadensis* is structurally most similar to *bottae*. If the Reese River valley were colonized from the south rather than from the Humboldt River to the north, it is possible that distribution through this area was never continuous with the remainder of the Humboldt River distribution, or that this area was isolated relatively early.

Much of the information presented above regarding genic differentiation among *T. townsendii* populations has a morphological counterpart from the analyses of cranial and pelage differentiation (Rogers 1991). However, relative to the genic data, morphological characters reflect a general pattern of more overlap with fewer strongly differentiated populations. As one would expect, some aspects of the biogeographic history of *T. townsendii* populations seem to be more closely reflected in the genic data. For instance, the four most divergent populations (Austin, Narrows, Grandview-*t.*, and Lovelock) all have an alternative allele as the predominant one at some locus. This kind of pattern is sometimes associated with isolation, whether it be a result of a founder event or range fragmentation. For some of these populations the features maintaining biogeographic isolation are obvious, although the mechanism by which isolation began is difficult to determine. The factors that might have contributed to the isolation of the Austin, Narrows, and Grandview-*t.* populations have already been discussed. Explaining the extent of differentiation seen in the *T. t. bachmani* population at Lovelock is more problematic. Since this area is part of the large and continuous Pleistocene Lake Lahontan, reasons for isolation and differentiation are not clear. However, it is peripherally located in the species range, and the nearest neighboring specimens examined in this study are from about 75 miles up the Humboldt River.

*Thomomys townsendii* is characterized not only by genetic homogeneity within populations, but by shifts in allele frequencies and appearance of rare alleles in high frequencies among populations. In addition, patterns of genic similarity between populations do not correspond to geographic distance, and populations of different subspecies or geographic subunits are often more similar than are other members of the same subspecies. These features do not suggest a broadly continuous species distribution historically. It is not surprising that this pattern instead suggests the effects of drift and independent evolution on population isolates that arose from the colonization of new areas or by the fragmentation of once more continuous habitat. Pocket gophers are strongly susceptible to drift due to small, effective population size and their inability to cross various environmental barriers, which may include other gopher species.

A reasonable explanation of the events in the origin and distribution of *Thomomys townsendii* begins with a relatively recent derivation from *Thomomys bottae*. In their analysis of *T. bottae* genic evolution, Patton and Smith (1981) discuss what appears to be a decreased rate of allozymic change in *T. townsendii*. However, they suggest that their results probably do not represent actual rate changes, but reflect low levels of within-population variation in *T. townsendii*. They hypothesize that this homogeneity is the result of a founder event and subsequent isolation, and later morphological studies suggest that the derivation from *bottae* was a relatively recent event (Patton and Smith 1989). While sufficient information is not available to pinpoint when and where *townsendii* arose from *bottae*, an origin from the southern part of the current *townsendii* distribution has been suggested. Davis (1937) noted the similarity between *bottae* and the most southern subspecies, *T. t. nevadensis*, and later stated that *townsendii* had probably moved into Idaho from the south (Davis 1939). In addition, in comparing *T. townsendii* to *T. bottae* populations, Patton and Smith (1989) show that *townsendii* is genetically most similar to *bottae* populations from central and southern California.

The low level of variation seen throughout *T. townsendii* suggests that stages of isolation and subsequent genetic drift followed the

divergence from *T. bottae*. Derivation from a single highly homozygous founding population would provide the genetic background necessary for dominant alleles to be maintained across the distribution despite discontinuities that inevitably arose after *T. townsendii* colonized the area. High interpopulation similarity suggests that low levels of genic variability were maintained as the founding population eventually dispersed through the Great Basin. The remnants of Pleistocene lakes served as a corridor for the dispersal of the species through northern Nevada, northeastern California, and southeastern Oregon and possibly into lake beds to the west of the present Oregon distribution, judging from fossil evidence (Allison 1966). Colonization of this area probably proceeded as a series of founder events with portions of the distribution becoming fragmented. The background of genetic homogeneity was maintained with diversification in the form of allelic variants. The fixed difference at the GOT-1 locus and the homogeneity seen among the Snake River populations suggest that this region was probably colonized by a single founding population from the Humboldt River region. Subsequent to dispersal of the species across the Snake River plain, discontinuities to the range arose and populations became slightly differentiated.

The relative homogeneity of the Snake River populations also suggests this region has had less time to differentiate than has the Humboldt River region. To demonstrate the relative difference in age among and between the Snake River and Humboldt River areas, estimated divergence times between populations were calculated and averaged for these two major geographic regions. Values generated for Nei's genetic distance and the methods of Nei (1971) as described by Patton and Yang (1977) were used for these estimates. An average divergence time between populations of these two geographic units is 255,400 years before present (maximum, 475,000 YBP; minimum, 190,000 YBP). The same value, calculated for populations of the Humboldt River region, is 92,083 years (maximum, 300,000 YBP; minimum, 5,000 YBP), while that for the Snake River populations is 27,143 years (maximum, 95,000 YBP; minimum, 0 YBP). As additional reference points, these divergence times were adjusted

using the albumin immunological distance method (Sarich and Cronin 1976, Sarich 1977), again following Patton and Yang (1977). These estimates show average divergence time between populations of the two river systems to be 1,072,680 YBP; among Humboldt River populations the average divergence time is 386,749 YBP, and within the Snake River system it is 114,001 YBP. While these values present very different approximations of divergence times within *Thomomys townsendii*, they do indicate a general time frame and what the sequence of events might have been. These estimates suggest that divergence among the Snake River populations occurred subsequent to the isolation between the northern and southern parts of the distribution and after diversification of the Humboldt River populations had begun.

Physical aspects of the two regions may have also contributed to the different degrees of morphological and genetic differentiation seen between the Humboldt River and Snake River regions. The greater biogeographic diversity and increased aridity of the Humboldt River region may have promoted isolation and differentiation in this area. Features of the habitat, particularly soil color and quality, may be more homogeneous along the Snake River drainage and influential in maintaining morphological homogeneity.

#### Systematic Conclusions

The genic data are the strongest indicators of differentiation that is greatest between the regions represented biogeographically by the Humboldt River and the Snake River drainage systems. One fixed difference (GOT-1) and the appearance of additional alleles at other loci separate these groups genically. Distinction between these two regions exists but is less apparent in discriminant function analyses of cranial characters (Rogers 1991). This pattern of differentiation does not correspond to the currently recognized seven subspecific units, originally described by Davis (1937). The data presented here and in the companion study (Rogers 1991) show that, in some cases, greater morphological and genetic differentiation has been found among samples within a subspecies than between subspecies. This is most apparent in the Humboldt River group, whereas the Snake River region represents

a more homogeneous unit. The variants observed in this study are usually quite subtle and do not warrant taxonomic distinction.

The population from Austin deserves special consideration here. These individuals are clearly differentiated morphologically (Rogers 1991) and genically. The historical biogeography of the *T. t. nevadensis* distribution and the presence of *T. talpoides* to the north suggest effective and possibly early barriers to gene flow with *Thomomys townsendii* populations to the north. The intermediate level of differentiation seen in the Austin sample is noteworthy in the context of understanding evolution within this species but does not warrant the level of distinction given to the two major geographic regions.

The absence of genetic variation in *Thomomys townsendii* is most remarkable considering the phylogenetic affinities between *townsendii* and *T. bottae*. The patterns of genetic variability found in *T. townsendii* and *T. bottae* are strikingly dissimilar. *Thomomys bottae* is characterized by extreme interpopulation differentiation in allozymes (Patton and Yang 1977), with an average Rogers' *S* between populations of .81. Similarly, karyotypic variability is great, consisting primarily of variation in arm number. These variants are the result of additions and/or deletions of heterochromatic arms (Patton and Sherwood 1982). Allozymic patterns of differentiation are concordant with geographic patterns of change in karyotype (Patton and Yang 1977, Patton and Smith 1981). Karyotypic and allozymic patterns are also concordant in *T. townsendii* in that they show homogeneity across geography. The type of chromosomal polymorphism found in *T. townsendii* is characteristic of species in the *bottae*-group and apparently does not act as a fertility barrier (Patton and Sherwood 1982). It is therefore unlikely that such variants are of much consequence in the evolutionary differentiation within *townsendii*.

In summary, *Thomomys townsendii* can be characterized as having undergone little intraspecific morphological and genetic differentiation since its origin from an ancestral stock, probably *Thomomys bottae*. Based on cranial, external, and pelage measurements, the species is quite homogeneous (Rogers 1991). The only chromosomal differences in *T. townsendii* involve a single unarmed pair

in an otherwise completely biarmed complement. The variation found in the genic data is primarily based on shifts in allele frequencies in some populations and the presence of rare alleles in others. *F*-statistics indicate that genic differentiation is greatest between populations and slightest between the subspecies within each geographic region. Subspecific integrity is not maintained by any units within the two regions. Given this high level of homogeneity, a conservative interpretation of the details of differentiation is necessary in assessing meaningful taxonomic categories within *Thomomys townsendii*.

The only pattern that is concordant among the data sets presented here and in the accompanying paper (Rogers 1991) is the break between the Snake River populations and those of Honey Lake Valley and the Humboldt River. Discriminant function analyses based on cranial characters show some differentiation between these two groups, although overlap exists (Rogers 1991). A fixed difference at the GOT-1 locus provides a clear split between these two regions despite their generally high genic similarity ( $S = .94$ ).

The evidence from this study suggests that only two geographical units can appropriately be given subspecific distinction. The ranges of these units correspond to (1) the Snake River Plain of Idaho and southeastern Oregon and (2) the Humboldt and Quinn River drainage systems in Nevada, southeastern Oregon (vicinity of Malheur Lake and Lake Alvord), and Honey Lake Valley, California. Within each of these regions there is local differentiation in some characters, but particular populations or subregions are not consistently delineated across many characters and modes of analysis (Rogers 1991). The currently recognized subspecies *T. t. bachmani*, *T. t. elkoensis*, *T. t. nevadensis*, and *T. t. relictus* are herein regarded as synonyms of *Thomomys townsendii nevadensis* Merriam, 1897, which has priority. The Snake River populations, representing *T. t. owyhensis*, *T. t. similis*, and *T. t. townsendii*, are treated as synonyms of *Thomomys townsendii townsendii* (Bachman 1839).

#### *Thomomys townsendii nevadensis* Merriam

*Thomomys nevadensis* Merriam, 1897, Proceedings of the Biological Society of Washington 11: 213. Type from Austin, Nevada; United States National Museum, Biological Survey Collection no. 23001.32413.

*Thomomys townsendii nevadensis* Bailey, 1915, North American Fauna 39:44.

*Thomomys relictus* Grinnell, 1926, University of California Publications in Zoology 30(1):2. Type from valley of Susan River two miles south of Susanville, Lassen County, California; Museum of Vertebrate Zoology no. 35271.

*Thomomys townsendii relictus* Grinnell, 1933, University of California Publications in Zoology 40(2): 137.

*Thomomys townsendii bachmani* Davis, 1937, Journal of Mammalogy 18(2): 150. Type from Quinn River Crossing, 4100 feet altitude, Humboldt County, Nevada; Museum of Vertebrate Zoology no. 7855.

*Thomomys townsendii elkoensis* Davis, 1937, Journal of Mammalogy 18(2): 151. Type from Evans, Eureka County, Nevada; Museum of Vertebrate Zoology no. 70583.

*Thomomys umbrinus bachmani* Hall, 1981, The Mammals of North America 1: 477.

*Thomomys umbrinus elkoensis* Hall, 1981, The Mammals of North America 1: 482.

*Thomomys umbrinus nevadensis* Hall, 1981, The Mammals of North America 1: 485.

*Thomomys umbrinus relictus* Hall, 1981, The Mammals of North America 1:492.

#### *Thomomys townsendii townsendii* (Bachman)

*Geomys townsendii* Bachman, 1839, (from Richardson's manuscripts) Journal of the Academy of Natural Sciences, Philadelphia 8(1):105. Type locality "Columbia River" is incorrect according to Bailey (1915:42), who feels the locality is near Nampa, Idaho; Academy of Natural Sciences Philadelphia no. 147.

*Thomomys townsendii* Allen, 1893, Bulletin of the American Museum of Natural History 5(5): 61.

*Thomomys nevadensis atrogriescus* Bailey, 1914, Proceedings of the Biological Society of Washington 27: 118. Type from Nampa, Idaho; United States National Museum, Biological Survey Collection no. 181, 196.

*Thomomys townsendii townsendii* Bailey, 1915, North American Fauna 39: 42.

*Thomomys townsendii townsendii* Whitlow and Hall, 1933, University of California Publications in Zoology 40(3): 255.

*Thomomys townsendii owyhensis* Davis, 1937, Journal of Mammalogy 18(2): 154. Type from Castle Creek, eight miles south of Oreana, Owyhee County, Idaho; Museum of Vertebrate Zoology no. 67490.

*Thomomys townsendii similis* Davis, 1937, Journal of Mammalogy 18(2): 155. Type from Pocatello, Bannock County, Idaho; Museum of Vertebrate Zoology no. 46507.

*Thomomys umbrinus owyhensis* Hall, 1981, The Mammals of North America 1: 489.

*Thomomys umbrinus similis* Hall, 1981, The Mammals of North America 1: 494.

*Thomomys umbrinus townsendii* Hall, 1981, The Mammals of North America 1: 495.

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## APPENDIX

### Specimens Examined

Listed below are specimens used in electrophoretic and karyotypic analyses. Boldface numbers preceding localities represent corresponding composite locality numbers. Sample sizes in parentheses represent the number used for electrophoretic analysis and the number karyotyped, respectively.

#### *Thomomys townsendii nevadensis*

CALIFORNIA: **Lassen Co.**, [30], Bird Flat Ranch, 3 mi. S, 2.7 mi. W Herlong, 4080 ft. (*n* = 27,5); [31], 4 mi. W Standish, 4110 ft. (*n* = 18,2).

NEVADA: **Elko Co.**, [10], 0.5 mi. SW Ryndon, 5100 ft. (*n* = 20,4); **Eureka Co.**, [11], Hay Ranch, 17 mi. SE Palisade, 5160 ft. (*n* = 19,3); **Humboldt Co.**, [5], Quinn River Crossing, 4100 ft. (*n* = 9,3); **Lander Co.**, [15], 5.5 mi. W Austin, 5700 ft. (*n* = 22,5); **Pershing Co.**, [3], Big Meadow Ranch, Lovelock, 4000 ft. (*n* = 16,3); [1], 2 mi. NW Valmy, 4450 ft. (*n* = 21,5).

OREGON: **Harney Co.**, [4], 4 mi. SW Narrows, 4200 ft. (*n* = 6,0).

#### *Thomomys townsendii townsendii*

IDAHO: **Bannock Co.**, [20], Floyd Johnson Ranch, 4 mi. NW Pocatello, 4500 ft. (*n* = 19,3); **Elmore Co.**, [22], 3 mi. E Grandview, 2800 ft. (*n* = 8,0); **Owyhee Co.**, [16], 7.5 mi. SE Grandview, 2600 ft. (*n* = 21,3); [17], 6 mi. SE Murphy, 3000 ft. (*n* = 4,1); **Payette Co.**, [23], 1.5 mi. NE Payette, 2200 ft. (*n* = 9,1); **Power Co.**, [19], 2.5 mi. NW American Falls, 4500 ft. (*n* = 10,2); **Washington Co.**, [23], 2.9 mi. SE Weiser, 2100 ft. (*n* = 1,0).

OREGON: **Malheur Co.**, [24], 2.5 mi. N Ontario, 2100 ft. (*n* = 20,1).

## ECOLOGICAL RELATIONSHIPS OF CURLLEAF MOUNTAIN-MAHOGANY (*CERCOCARPUS LEDIFOLIUS* NUTT.) COMMUNITIES IN UTAH AND IMPLICATIONS FOR MANAGEMENT

James N. Davis<sup>1</sup> and Jack D. Brotherson<sup>2</sup>

**ABSTRACT.**—Curleaf mountain-mahogany is a widely distributed shrubby tree of western North America. Well-developed stands are most often found on warm, dry, rocky ridges and slopes at high elevations on mostly southern exposures. It can, however, be found on all exposures. The species appears to be indifferent to substrate with soils which are invariably shallow and of low fertility. However, the nitrogen-fixing root nodules help overcome soil deficiencies. This highly palatable species is preferred by mountain sheep, mountain goats, deer, and elk. Its nutritive value (about 12% protein) and digestibility ratings (around 50%) in the winter are high when compared with most other associated winter browse species.

Early research with curleaf mountain-mahogany basically dealt with two major management problems: (1) how to increase available forage production on old, even-aged stands too tall for big game to browse, and (2) how to increase reproduction in these same communities. Selective dozer thinning, sometimes in conjunction with the seeding of fast-growing plants, appears to be a promising management technique providing browse until the younger curleaf becomes established.

**Key words:** *Cercocarpus*, mountain-mahogany, habitat relationships, management.

Curleaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.) is a widely distributed shrubby tree of western North America, ranging from Helena, Montana, south to San Pedro Martin in Baja California, and from the Bighorn Mountains near Sheridan, Wyoming, to almost the West Coast in southwestern Oregon (Fig. 1). Its distribution is from 610 m to 1372 m in elevation in the northern and northwestern parts of its range and to 3000 m or more in the most southern parts of its range (USDA Forest Service 1937, Martin 1950). Duncan (1975) studied populations in Montana and found them to exist between 1200 m and 2100 m, with a mean of 1700 m.

Curleaf mountain-mahogany is often associated with sagebrush, pinyon pine, juniper, scrub oak (mountain brush), ponderosa pine, and spruce-fir (Martin 1950). Tidestrom (1925) states that in central Nevada the species frequently takes the place of ponderosa pine and aspen at medium elevations, where it sometimes forms a noticeable transition community between pinyon and limber pine. Across the Great Basin, curleaf mountain-mahogany actually occupies a narrow but unique position between the lower fringes

of the conifer zone and the upper edges of the desert steppe. In California, but still within the Great Basin, Brayton and Mooney (1966) found curleaf mountain-mahogany populations centered about 2000 m elevation in the subalpine zone. Here it occupied limestone, dolomite, sandstone, and granitic soils with a pH range of 6.5–8.4. Similar results were obtained in studies done by Miller (1964) in Wyoming and Scheldt (1969) in Idaho.

The best-developed stands of curleaf mountain-mahogany are routinely found on warm, dry, rocky ridges or slopes at high elevations, primarily western or southern exposures (Tidestrom 1925, USDA Forest Service 1937, Martin 1950, Miller 1964, Brayton and Mooney 1966, Scheldt 1969, Thompson 1970, Duncan 1975). These stands are characteristic in isolated patches but infrequently will be found singularly or in continuous and extensive communities.

Taxonomic variability in the genus *Cercocarpus* has long been noted, and at present there are several opinions concerning its classification. Martin (1950) revised the genus *Cercocarpus* and delimited the *ledifolius*

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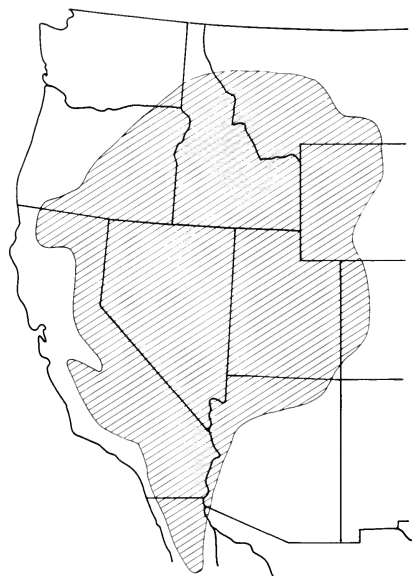


Fig. 1. Curleaf-mahogany distribution.

lifeforms into three varieties. Others, however, have elevated these varieties into species rank (Tidestrom 1925, USDA Forest Service 1937, Martin 1950, Smith 1964, Brayton and Mooney 1966). Welsh et al. (1987) combined the varieties *typicus* and *intercedens* into *C. ledifolius*, while giving the variety *intricatus* separate species status. Holmgren (1987) determined that Nuttall's holotype for *C. ledifolius* was actually the more narrow-leaved taxon, while the more broad-leaved taxon had no name at any level. Therefore, Holmgren gave the more wide-leaved variety the name *C. ledifolius* var. *intermountainus*. Those interested in this taxonomic question can also refer to Stutz (1990). Because of the previous and confusing taxonomic treatments of *Cercocarpus ledifolius* by others, in this paper we do not distinguish between the two varieties of curleaf mountain-mahogany. But the somewhat indistinct taxonomic interpretations can be summarized in the following manner. The narrow-leaved variety (*C. ledifolius* var. *ledifolius*) is widely distributed

throughout the more northern and eastern portions of its distribution. The wide-leaved variety (*C. ledifolius* var. *intermountainus*) is commonly more central and southern in its distributional range, with both varieties found overlapping through the central portions of its range. The classification of Welsh et al. (1987) is followed in this paper, and any plant with elliptic leaves over 12 mm in length is considered to be *Cercocarpus ledifolius* Nutt.

Common names for *C. ledifolius* vary with location. Western pioneers called members of the genus mountain mahogany. The Federal Trade Commission, however, has since ruled that the name "mahogany" should not be used to designate any other genus except *Sweetenia*. The Forest Service checklist gives "Cercocarpus" as the common name of the genus (Hayes and Garrison 1960). But, several common names are still used when referring to *C. ledifolius* (i.e., desert mahogany, leatherleaf mahogany, and curleaf mountain-mahogany).

Curleaf mountain-mahogany is highly palatable to elk and deer (Smith 1950, Hoskins and Dalke 1955, Davis 1982). Because its nutritive value and digestibility ratings are high when compared with associated browse species, it merits attention in big game management (Smith 1952, 1957, Bissel and Strong 1955, Welch 1981). Welch and McArthur (1979) noted that curleaf mountain-mahogany is one of only a few shrubs that exceed the protein requirements of wintering deer. Other authors also consider it an important winter forage plant (Tidestrom 1925, USDA Forest Service 1937, Liacos and Nord 1961, Scheldt 1969).

Dependence on curleaf mountain-mahogany for winter forage can cause problems for wildlife because live branches are often beyond reach of browsing animals. Also, among populations in Utah, winter snows limit mid-winter access to curleaf mountain mahogany growing at high elevations. But, when curleaf mountain-mahogany is available, it becomes an important forage species for mule deer and elk (Mitchell 1951, Smith 1952, Smith and Hubbard 1954, Richens 1967, Tueller 1979). Curleaf mountain-mahogany has been noted as the third most important winter browse species for mule deer in northeastern Utah (Richens 1967) and also in eastern Oregon and

Washington (Mitchell 1951). It is especially essential for mountain goat survival in Idaho (Kuck 1980). In Utah, on one particularly critical mountain goat wintering area, it is the only browse available to about 80 animals (personal observation).

Most curleaf mountain-mahogany investigative research has dealt with two major management problems: (1) how to increase available forage production on old, even-aged, out-of-reach curleaf mountain-mahogany communities, and (2) how to increase reproduction in these same curleaf mountain-mahogany communities.

In the late 1940s and early 1950s in Grant County, Oregon, different pruning techniques were tried as a means of improving forage production for wintering wildlife. Some of the methods showed promise, but most did not, and all were expensive (Lemons, n.d.).

Many other researchers have since investigated different pruning methods (Garrison 1953, Neff 1963, Thompson 1970, Shepherd 1971, Ormiston 1978, Austin and Urness 1980). Generally, clipping 50–75% or even as much as 98% of the limbs increased twig production the following year. In some cases rejuvenated twig production appeared to decrease after three or more years. The consensus was that pruning should be done during spring or early fall, and then mostly on the younger age classes. Pruning done during the winter, especially on older trees, caused death the next summer. Thompson (1970) noted that reproduction appeared to be better under individual trees that had been pruned. Pruning costs ran as high as \$120/ha (Ormiston 1978).

Phillips (1970) prepared a summary of curleaf mountain-mahogany rehabilitation projects on the Region 4 National Forests. The summary stated that in the 1960s the major problems in curleaf communities were extensive highlining of older even-aged communities (which produced very little available browse) and little or no reproduction (Phillips 1970). Of special note was the bulldozing of strips parallel and perpendicular to the slope to decrease competition and allow young mahogany plants to become established. The treatment resulted in a spectacular increase in associated browse species that produced forage much faster and in greater quantities

than did curleaf mountain-mahogany. At the same time nearby older curleaf mountain-mahogany provided excellent cover.

In a U.S. Forest Service report, Ferguson and Klemmedson (1965) examined most curleaf mountain-mahogany ranges from southwestern Montana through southern Idaho. They found nearly all of the curleaf communities in poor condition resulting from excessive use by wildlife and livestock. Personnel from the Forest Service and Montana Fish and Game Department stated that without curleaf mountain-mahogany it would be almost impossible to maintain high populations of deer in the area of Beaverhead County, Montana. Again, the major problems observed were the failure of curleaf to reproduce and the occurrence of edible browse beyond reach of browsing animals.

Winter forage areas are a major limiting factor for large deer populations in much of the Intermountain West. Available or suitable wintering areas are generally low in productivity, making their rehabilitation and management difficult. Current encroachment of human populations onto many of these winter ranges further complicates their management.

When it is desirable to maintain or increase game animal populations, the manager has but two alternatives: either to improve and/or to expand the winter range. Expanding the size of winter range is usually not feasible, but improvement can often be achieved. Successful improvement practices require an understanding of the structure and dynamics of the plant communities in question. In the case of curleaf mountain-mahogany communities, such information is very limited. Additional ecological investigations are needed if managers are to more effectively manage this community type.

The authors' objective is to consolidate into one article information concerning the synecology of curleaf mountain-mahogany communities gained through direct field studies along with correlated information from other authors of the last 20 or more years. Such a publication should permit better management and understanding of curleaf communities and the big game populations that are totally or partially dependent on these communities for winter food and shelter.

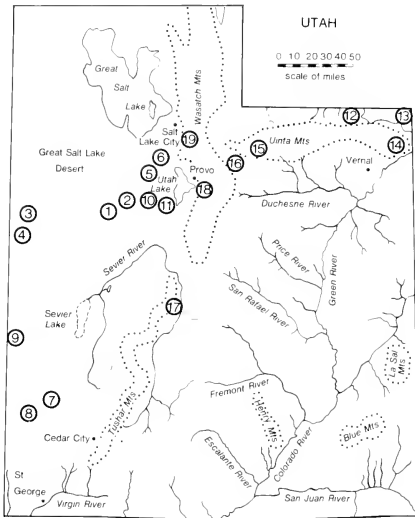


Fig. 2. Location of the 19 curleaf mountain-mahogany study areas.

## METHODS

Nineteen communities of curleaf mountain-mahogany were selected for their large size and homogeneous nature (Fig. 2). Study plots of .04 ha were established within each community. Elevation, slope, and exposure for each plot were determined. Exposure values were transformed according to Beers et al. (1966), allowing the use of exposure as an independent variable in multiple regression analysis. Beers et al. (1966) used a northeast exposure for their optimum timber growth. However, according to our site quality index, curleaf mountain-mahogany has its optimum growth on southwest exposures. Therefore we transformed the compass readings using the following equation:

$$\text{Southwest optimum} = \text{COS} (225 \\ - \text{compass reading in degrees} + 1)$$

Twenty-five .25-m<sup>2</sup> quadrats in a 5 × 5 grid were equally spaced within the plot to help determine density, frequency, and cover of all plant species. Cover values were estimated as suggested by Daubenmire (1959). Trace

species were recorded. A trace species was regarded as any plant species not occurring within any of the .25-m<sup>2</sup> quadrats but still occurring inside the study plot.

The most prevalent or important plant species were determined by multiplying constancy (in percentage) of each species (Oosting 1956) by average frequency (in percentage) in all stands (Curtis 1959).

A site quality index was based on stem diameter (measured 30 cm aboveground) divided by age and multiplied by 1,000. Stem diameter was used instead of tree height because of the dwarflike tree habit of curleaf mountain-mahogany on many sites. Preliminary analyses demonstrated that stem diameter was better related to stem volume than was height in regression analyses.

All curleaf mountain-mahogany plant heights within each .025-ha plot were measured to the nearest tenth of a meter. Stem basal diameter was recorded for each plant. The number of separate stems per tree was also determined at this same height.

Stand age for curleaf mountain-mahogany was estimated by cutting five basal stems, one each (the largest if plants were multiple stemmed) from five different trees within the study plot. Stem diameter ranged from 2.5 to 20 cm. Even when sanded and stained, stems were difficult to age: annual rings are narrow and indistinct (Saul 1952, Dale 1968). Stems were independently counted at least twice to insure accuracy in estimates of age. Only stands 10 through 19 were aged. Ages of stands 1 through 9 were estimated using the following equation derived from stems taken from stands 10 through 19: age of tree =  $m$  (stem diameter) +  $B$ , where  $m = 17.8$  (slope) and  $B = 11.2$  (y intercept),  $R^2 = .67$ , which was significant (.01) for this equation.

Soil samples were taken at 5 of the 25 quadrats in each stand and were located at the corners and center of each study plot. Samples were taken to a depth of approximately 15 cm, and the 5 samples were combined for analysis. Samples were analyzed for texture, pH, and soluble salts. Soil depth, taken as the average of the 25 readings, was determined at each of the quadrats where soil samples were taken.

Similarities and differences in the vegetative parameters between the study sites were



TABLE 1. Physiographic characteristics of the curlleaf mountain-mahogany communities sampled in Utah.

Community characteristics	High	Low	Mean	Standard deviation
Elevation (m)	2725.00	2134.00	2397.60	172.80
Percent slope	81.00	18.00	45.40	15.90
Exposure <sup>a</sup>	1.98	.00	—	—
Soil depth (dm)	3.20	.60	1.64	.77
Percent sand	91.00	38.00	58.30	12.90
Percent silt	44.00	6.00	25.50	8.20
Percent clay	31.00	3.00	16.20	61.00
Soil pH	7.80	5.90	6.90	.60
Soil soluble salts (ppm)	550.00	92.00	278.30	113.00

<sup>a</sup>Numbers relate to Beers et al. (1966) transformations (2.00 equals Southwest)

calculated using Sorenson's index of similarity (Sorenson 1948, Dix and Butler 1960).

Cluster analysis techniques (Sneath and Sokal 1973) were applied to the interstand similarity values. In this way, interstand compositional similarities were graphically represented. Multiple stepwise regression and correlation analyses were made using standard programs available at Brigham Young University.

## RESULTS AND DISCUSSION

### Physiographic Characteristics

Physiographic characteristics of the curlleaf mountain-mahogany communities examined in this study are reported in Table 1. Elevation ranged from 2134 m to 2725 m and averaged 2398 m.

Curlleaf mountain-mahogany appears to occur at a higher average elevation in Utah, Nevada, and east central California than anywhere else in its range. Stands of the species, while occurring below 2134 m in Utah, are rarely large enough to accommodate study plots of the size employed in this study. Extensive stands were observed above 3050 m in the Deep Creek Mountains of western Utah, but they were not sampled. Brayton and Mooney (1966) found curlleaf mountain-mahogany communities centered at elevations just above 2800 m in the White Mountains of east central California. Such high-elevation stands are not unusual on the higher southern mountain regions of the Great Basin. Lewis (1971) reports well-developed curlleaf mountain-mahogany communities occurring from 2230 to 2787 m in the Ruby Mountains of north-eastern Nevada.

In Montana, Duncan (1975) reports that curlleaf mountain-mahogany forms a distinct

community type over an elevational range of 1165–2152 m. Miller (1964) in Wyoming and Scheldt (1969) in Idaho found very similar elevational ranges. Dealy (1975) found curlleaf mountain-mahogany ranging from 1375 to 2271 m in the area of southeastern Oregon. Lower altitude preferences for the species near its northern range limit are to be expected.

Well-developed stands are usually found on steeply sloping land; slopes averaged 45% in Utah. Miller in Wyoming (1964), Scheldt in Idaho (1969), and Duncan in Montana (1975) had similar average slopes of 48, 53, and 48%, respectively. Sampled stands occurred on all exposures, as was also reported by Miller (1964), Brayton and Mooney (1966), Scheldt (1969), Dealy (1975), and Duncan (1975). Although occurring on all exposures, curlleaf mountain-mahogany appears most commonly on south and southwest exposures.

True mountain-mahogany (*Cercocarpus montanus* Raf.) communities in Utah are reported by Anderson (1974) to range from 1511 to 2195 m. Generally then, the altitudinal ranges of curlleaf mountain-mahogany and true mountain-mahogany overlap little in Utah. These congeners exhibit little difference, however, with respect to slope steepness and exposure preferences.

### Edaphic Characteristics

Soils underlying the curlleaf mountain-mahogany communities studied were invariably shallow, with an average penetrometer depth of 1.65 dm. This corresponds closely to results of studies by Miller (1964) and Duncan (1975). The soils are commonly sandy loams; however, a few stands occurred on loam, clay loam, and sandy loam sites. Soil reaction tended to be circumneutral (modal pH of 7.1),

but individual stands were observed on sites as acidic as 5.9 and as basic as 7.8. Miller (1964) and Duncan (1975) noted a pH of 7.6 and 7.5 in Wyoming and Montana, respectively. Soluble salts were low in all the soils analyzed, with a range of 92–550 ppm. These figures correspond to the findings of Miller (1964), Brayton and Mooney (1966), Scheldt (1969), and Duncan (1975). Brayton and Mooney (1966) also reported occurrences of this species in California on shallow soils of low fertility where it appeared to be indifferent to substrate. Duncan (1975) found the species on soils in Montana that were very low in phosphorus and only intermediate in respect to potassium.

Youngberg and Hu (1972) reported in an Oregon study that curleaf mountain-mahogany produces root nodules capable of fixing nitrogen. They also discovered that foliage from nodulated plants has the highest amounts of nitrogen. Lepper and Fleschner (1977) found that soils supporting limber pine-curleaf mountain-mahogany stands have higher percentages of total nitrogen than soils beneath similar limber pine stands without the curleaf mountain-mahogany association. They concluded that the ability to fix nitrogen is a frequent occurrence in extreme or pioneer habitats.

If the capacity to fix nitrogen is universal in curleaf mountain-mahogany, it would help to explain how the species can successfully occupy the infertile sites that it regularly colonizes.

In respect to soil preferences, curleaf mountain-mahogany and true mountain mahogany diverge widely in Utah. Anderson (1974) found the most common textural class for the latter species to be clay loam. Soil depths were almost twice as great in true mountain mahogany stands (Anderson 1974) as in the curleaf stands reported here. Further, this study also indicates that curleaf mountain-mahogany occurs on less basic and less saline soils than does true mountain mahogany.

#### Synecological Characteristics

Vegetative parameters for curleaf mountain-mahogany communities are listed in Tables 2, 3, and 4. Canopy coverage values varied from 20% to as high as 63%, with a mean of 40%. The mean canopy height per

site varied from 2.0 to 4.6 m, with an average of 3.4 m for all sites combined. Curleaf mountain-mahogany densities ranged from a high of 417 plants per ha to a low of 60.7 plants per ha, with a mean of 171.1 per ha.

In Montana, curleaf mountain-mahogany densities were much greater than those observed in this study. Densities varied from 472 to 21,627 individuals per ha, with a mean of 3,397 per ha (Duncan 1975). Scheldt (1969), in Idaho, showed a mean of 511 trees per ha.

Data on other variables obtained during the sampling were analyzed using multiple regression. These entities, along with their influencing factors and their coefficients of determination, are listed in Table 5. Those with 50% or more of the variation accounted for were: mean canopy cover ( $R^2 = .74$ ), mean canopy height ( $R^2 = .64$ ), relative percent frequency of shrubs per stand ( $R^2 = .58$ ), relative percent frequency of biennial forbs per stand, ( $R^2 = .66$ ), and relative percent frequency of *Carex* species per stand ( $R^2 = .55$ ). Mean canopy cover per stand appeared to be most affected by moisture-related factors because slope, exposure, and percent sand within the soil together accounted for 64% of the .74  $R^2$  value. Mean height per stand was most affected by soil pH ( $R^2 = .12$ ) and soluble salts ( $R^2 = .40$ ). Curleaf mountain-mahogany density appeared not to be affected ( $R^2 = .34$ ) by moisture-related factors.

The most important or prevalent species on the curleaf mountain-mahogany study sites are listed in order of importance in Table 4. The 23 prevalent species of this study account for only 16% of the 148 species encountered in the study. But, they contribute more than 90% of the living cover in an average stand. The prevalent species are predominantly perennial (91%). More than 80% of the living cover (Table 3) in an average stand is contributed by woody or suffrutescent species. Perennial grasses account for only 7% of the cover. Perennial dicotyledonous herbs and annuals account for the remainder, with perennials furnishing about twice as much cover as annuals (Table 3). The large contribution of woody plants and perennial grasses in the community is probably related to the xeric nature of the sites dominated by curleaf mountain-mahogany (Harner and Harper 1973, Yake and Brotherson 1979). The dominance

TABLE 2. Curleaf mountain mahogany stand characteristics determined from the 19 stands studied in Utah.

Curleaf mahogany characteristics	High	Low	Mean	Standard deviation
Trees/ha	417.00	60.00	171.30	81.90
Percent canopy cover	63.30	19.60	40.00	13.40
Mean canopy height (m)	4.70	2.10	3.40	.80
Mean stem diameter (cm)	18.50	5.10	10.40	3.20
Mean stems/tree	5.60	1.70	3.40	1.20
Seedlings/0.025 ha	23.00	.00	3.70	7.10
Mean age/site	142.92	47.51	85.47	23.09
Site quality index	772.00	290.00	486.30	93.20

TABLE 3. Vegetational characteristics of curleaf mountain-mahogany communities studied in Utah.

Vegetational characteristics	High	Low	Mean	Standard deviation
Species/stand	37.00	15.00	22.90	5.80
Species/quadrat (mean)	5.40	1.60	3.70	1.20
Percent understory cover	70.00	7.00	33.40	15.90
Percent canopy cover	93.00	30.00	66.60	15.90
Percent shrub cover	55.00	1.00	17.30	13.40
Percent perennial grass	35.00	1.00	7.20	8.70
Percent perennial forb	22.00	1.00	5.90	5.90
Percent annual cover	27.00	.00	3.20	6.20
Percent sedge cover	1.00	.00	.20	.40

TABLE 4. Prevalent plant species of Utah curleaf mountain-mahogany communities. Species are arranged in decreasing order of average importance in the community.

Species	Life-form	Percent constancy (a)	Mean percent frequency per stand (b)	Prevalent index (a × b)
<i>Cercocarpus ledifolius</i>	tree	100	69.89	6989
<i>Symphoricarpos orcophilus</i>	shrub	89	20.63	1836
<i>Agropyron spicatum</i>	grass	79	16.63	1314
<i>Berberis repens</i>	shrub	74	14.74	1091
<i>Artemisia tridentata</i>	shrub	74	6.74	499
<i>Bromus tectorum</i>	annual grass	47	9.47	445
<i>Arenaria kingii</i>	subshrub	42	10.53	442
<i>Poa fendleriana</i>	grass	37	6.95	257
<i>Amelanchier utahensis</i>	shrub	53	4.84	257
<i>Oryzopsis hymenoides</i>	grass	47	4.84	227
<i>Erigeron</i> spp.	shrub	37	6.11	226
<i>Pachistima myrsinites</i>	shrub	26	7.37	192
<i>Chrysothamnus viscidiflorus</i>	shrub	47	4.00	188
<i>Penstemon</i> spp.	forb	32	5.47	175
<i>Hesperochloa kingii</i>	grass	32	5.05	162
<i>Quercus gambelii</i>	shrub	32	4.63	148
<i>Collinsia parviflora</i>	annual forb	21	6.68	140
<i>Poa secunda</i>	grass	21	5.89	124
<i>Stellaria jamesiana</i>	forb	16	7.05	113
<i>Pinus monophylla</i>	tree	37	2.95	109
<i>Festuca ovina</i>	grass	21	4.00	84
<i>Eriogonum microthecum</i>	shrub	26	3.16	82
<i>Agropyron trachycaulum</i>	grass	21	3.58	75

TABLE 5. Results of multiple regression analysis ( $R^2$ ) on measured characteristics of curleaf mountain-mahogany communities.

Dependent variables	Measured community environmental characters										
	Slope	Exposure	Elevation	Soil depth	Soil pH	% sand	% fines	% silt	% clay	Soluble salts	Coef. of determ.
Curleaf mountain-mahogany											
Mean cover/stand	-.35	-.07		-.06	-.04	-.22					.74
Mean height/stand	-.05			-.07	-.12					.40	.64
Mean stems/tree	.03	-.01	.02			.08				-.52	.66
Subbasal area/stand	-.13	.22	.18		.10						.63
Site index (diameter/age)		.04	.34		-.05		.01			.30	.74
Mean species/quadrat	-.01		.04	.24							.29
Sum % cover for all species/stand			.06	.05	.05		.34			.04	.54
Sum % cover shrubs/stand		-.18			.23		.01				.42
% relative freq. trees	.04	.07		-.15	-.01			.05	.06		.38
% relative freq. shrubs		-.14	.07		.05		.06			.25	.58
% relative freq. peren. forbs	-.03		.27	.22			-.03			.05	.60
% relative freq. biennial forbs	-.03			.15	.03		-.45				.66
% relative freq. annual forbs	-.02	.08					.03			-.14	.27
% relative freq. perennial grass				.04			.17				.21
% relative freq. annual grass		.10	-.07	.10			.06			-.02	.35
% relative freq. <i>Carex</i> spp.	-.10		.04				-.39			.02	.55

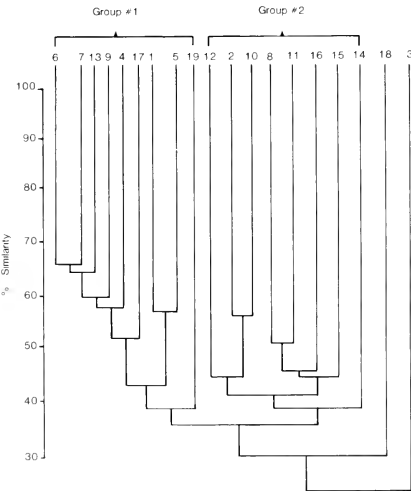


Fig. 3. Clustering of the 19 curleaf mountain-mahogany study areas based on cover composition and 40% similarity.

and variety of woody species in the community help to insure that forage of good variety and quality will remain exposed to game animals even with considerable snowcover on the ground. Curleaf mountain-mahogany

stands on south and southwest exposures are known to attract concentrations of big game animals during early and late winter or throughout a mild winter in Utah.

Clustering techniques (Sneath and Sokal 1973) based on cover composition of the vegetation show two major groups clustering above the 40% similarity level (Fig. 3). One group (designated 1) contains eight stands, and the other group (designated 2) contains seven stands. An unpaired *t* test was used to test for significant differences in vegetative and environmental characteristics between the two cluster groups. Results indicated that curleaf mountain-mahogany canopy cover, percent of soil fines (clay and silt), and percent of sand were the only measured variables that exhibited significant differences with respect to the two groups.

To determine which environmental variables exerted the most influence on curleaf mountain-mahogany performance, the site quality index was correlated via multiple stepwise regression with values for several environmental variables. The analysis showed that elevation, soluble salts, exposure, soil pH, and percent of fines together accounted for 74% of the variation in performance of curleaf mountain-mahogany in the stands sampled. Of this variation, 85% of the total is accounted for by elevation and soluble salts (Table 5).

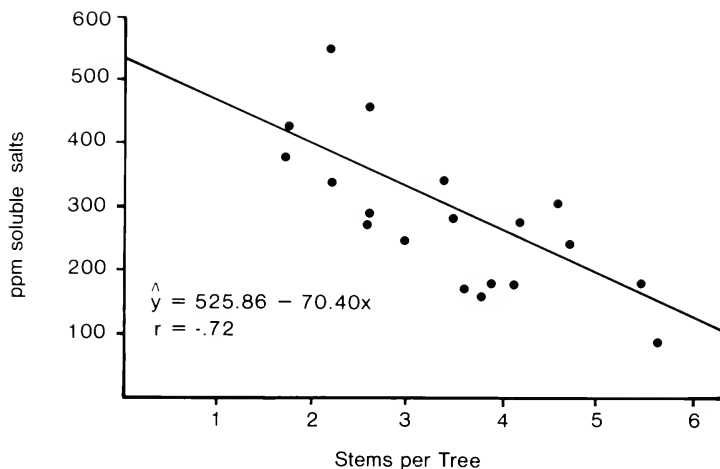


Fig. 4. Regression plot showing relationship between curleaf mountain-mahogany branching habit and soluble salts.

The equation for this relationship is: site quality =  $0.56x_1 + 0.09x_2 + 3.2x_3 - 48.5x_4 + 0.66x_5 - 156.6$  ( $x_1$  = elevation,  $x_2$  = soluble salts,  $x_3$  = exposure,  $x_4$  = pH,  $x_5$  = percent fines).

Although the site quality index identifies those sites where the species grows most rapidly, it is poorly correlated with available browse for big game because the "highest quality sites" in this study characteristically produced curleaf individuals that are more treelike than shrublike in habit.

#### Growth Form

Curleaf mountain-mahogany growth habit varied from treelike (1.75 stems per tree) to shrublike (5.6 stems per tree). Varying growth forms were also observed in Idaho (Scheldt 1969), Wyoming (Miller 1964), and Montana (Duncan 1975). Stem diameter per tree ranged from 5.0 cm to 18.5 cm, with an average of 10.6 cm (4.1 in). Regression analysis revealed that the branching habit of curleaf mountain-mahogany in Utah is significantly correlated with soluble salts and percent of sand in the soil (Figs. 4, 5). This relationship could be important when considering establishment of curleaf mountain-mahogany onto new areas. Knowing the amount of sand and soluble salts may allow one to estimate

whether or not the plants would develop shrub- or treelike habits. The effect of soluble salts and sand content on the mean number of stems per tree is made even more evident in multiple stepwise regression. Soluble salts alone accounted for 52% of the total 66% variation, or 79% of the total variation accounted for by the regression (Table 5). Without common garden studies, one cannot determine whether this branching habit is an environmentally adaptive response or a fixed genetic response.

The average canopy height per site in this study varied from 2.0 to 4.6 m, with a mean of 3.4 m. This may be misleading, for many trees were observed to be over 6 m tall on some of the sites studied. For example, site 9 near Baker Lake Trail in the Humboldt National Forest had trees over 9 m tall. Scheldt (1969) found the average height to be 2.9 m in his Idaho study. In contrast, Duncan (1975) found that sites in Montana west of the Continental Divide had an average canopy height of 1.7 m, while sites east of the Divide had an average canopy height of only 0.9 m.

#### Age and Reproduction

Mean ages for curleaf stems on the 19 study sites ranged from 48 to 143 years, with an average age for all study sites of 85 years.

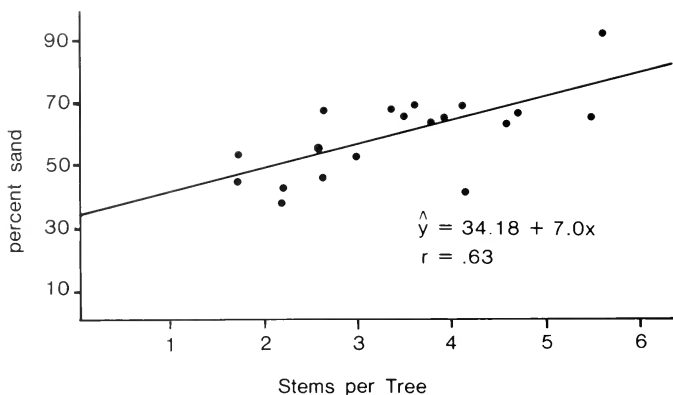


Fig. 5. Regression plot showing relationship between curleaf mountain-mahogany branching habit and percent sand.

Age distributions (Fig. 6) indicate that 58% of the individuals sampled fall between the ages of 56 and 109 years.

Dealy (1975) rarely encountered trees larger than 25 cm in diameter in Oregon. Over 90% of all trees sampled in his study were less than 20 cm in diameter. In this study, 74% of the trees had diameters 15 cm or less, while 26% were over 15 cm in diameter (109 years of age or older). Thus, Utah stands appear to be older in average age than the Oregon stands. These comparisons can be made between Oregon and Utah because a line midway between Dealy's (1975) two regression lines, one for dry sites and one for moist sites, would estimate a 20.3-cm stem to be 130 years old. Using the diameter-age regression equation developed in this study, one could estimate the age of the same 20.3-cm stem to be 131 years. Such remarkable similarity between regression equations would suggest that curleaf mountain-mahogany growth is similar between Oregon and Utah.

Forty-seven percent of the areas sampled had no trees in the size class less than 2.5-cm (20-year age class) (Fig. 6), indicating little or no reproduction on these sites. This could be due to shade intolerance of curleaf mountain-mahogany seedlings, competition for water and mineral nutrients with adult curleaf mountain-mahogany and other understory species, autotoxicity of litter to seedlings of

the species, or overutilization by wildlife. Such low rates of reproduction in a species whose individuals are capable of living to be well over 723 years (estimated age of 100-cm-diameter stem near site 17) may not, however, be a serious deficiency. Individuals of great longevity should be able to find ample opportunity to replace themselves over an extended period.

Ages reported for curleaf mountain-mahogany in the Montana study (Duncan 1975) were much younger than those for Utah or Oregon. Trees in sites west of the Continental Divide had a mean age of 31 years, with a range of 5 to 85 years. Trees on sites east of the Divide were still younger, with a mean age of only 20 years. Eight percent of the individual samples were classified as young, mean age 10.8 years. Sixty-two percent were classified as mature, mean age 39.5 years. Thirty percent were classified as decadent, mean age 49.9 years.

In this study about 10% of the individuals were considered decadent. Mean age of decadent (more than 25% of the crown was dead) individuals in Utah was about 167 years. This lower percentage of decadence may possibly be attributable to the difference in plant height: taller trees would not suffer as much browsing damage as would the shorter Montana plants. The oldest tree recorded in Duncan's (1975) study was 130 years. The oldest stands we are aware of are from central and

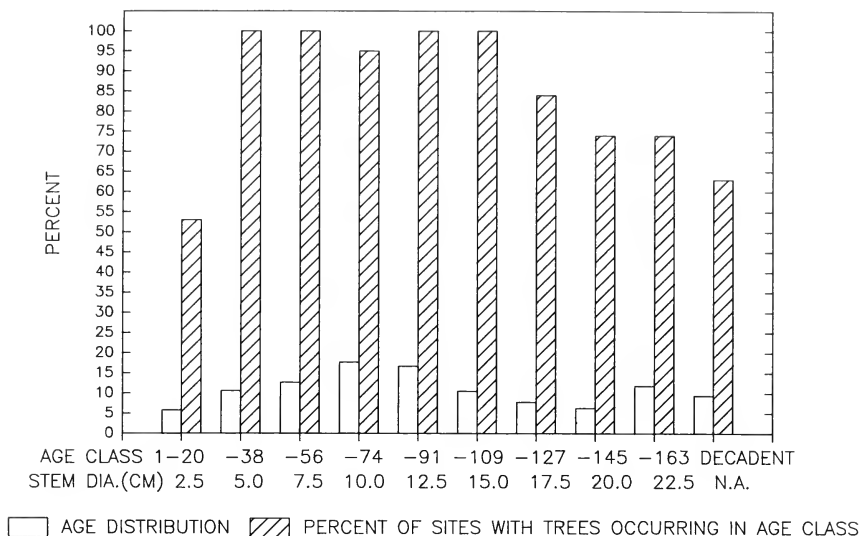


Fig. 6. Curleaf mountain-mahogany distribution of stem-diameter classes and their associated age for the 19 stands sampled.

western Nevada; ages range from 134 to 482 years with a mean of 352 years (Schultz et al. 1990).

Once germination has taken place, the seedlings appear to be well adapted for establishment in xeric habitat. Dealy (1975) reported that curleaf seedlings had a mean taproot length of 0.97 m after 120 days. The mean top height for the seedlings after 120 days was slightly less than 2.5 cm, with a mean leaf area of 4 cm<sup>2</sup>/seedling.

Reproduction on all study sites was generally poor, ranging from no seedlings (in 47% of the study plots) to 568 seedlings per ha in plot 13. The average number of seedlings per plot was 222 per ha. Duncan (1975) reported an average of 134 seedlings per ha, with a range of 0 to 660 seedlings per ha in Montana. Sixty-eight percent of her study areas had no seedlings. The great variation in reproduction would indicate that a critical combination of environmental conditions must exist for germination and seedling establishment. Scheldt and Tisdale (1970) and Dealy (1975) also observed that insect predation on mature seeds is a common occurrence. Good seed crops occur only every 2 to 10 years accord-

ing to Plummer et al. (1968). Variations in seed production from year to year could be one explanation for poor reproduction. Dealy (1975) found that no special chemical treatment was needed for germination of the seeds other than being stratified in a moist medium at 4 C over a 220-day period. He obtained 88% germination after such treatment. This suggests that a wet, somewhat mild winter is required for good stratification and that an unusually wet spring-summer is needed for good seedling germination and establishment.

Scheldt and Tisdale's (1970) counts of seedling survival through the first summer revealed that most mortality was due to drought. Winter mortality, also high, was due to grazing, mostly thought to be rabbits. The lack through time of proper combinations of critical parameters needed for germination and growth of young curleaf mountain-mahogany plants may help to explain why reproduction is so poor on most curleaf mountain-mahogany sites.

#### MANAGEMENT IMPLICATIONS

The management of curleaf mountain-mahogany is difficult because the species

does not resprout after burning or chaining and is very troublesome to establish from seed. These characteristics do not leave many options for management manipulation. The major problem confronting the manager will be, What do you do with old, decadent communities of curlleaf with out-of-reach browse? There are no feasible quick-fix methods for this problem. The pruning studies are examples of feasible but basically impractical treatments for increasing production. The best overall approach to this problem, in the long term, would be to thin or take out old trees in small, randomly placed and shaped openings. This would allow associated shrub species to be released while allowing openings for curlleaf seedlings to become established. The thinning process could be done by selective dozing or chaining, depending on the size and shape of the openings wanted within a stand. Release of associated species would give some immediate relief with respect to overuse of the curlleaf mountain-mahogany and also allow younger age classes of curlleaf mountain-mahogany time to become available. Some communities of curlleaf may lack associated browse species; here selective removal would probably only promote establishment of young seedlings. If other browse species are wanted, especially species that grow more rapidly, seed dribblers (placed over both bulldozer tracks) could be used to plant species that would provide browse much sooner than the slow-growing curlleaf. But, such species should not be planted in densities so high as to hamper curlleaf establishment; curlleaf seedlings are not strongly competitive. This close association could also be of benefit because curlleaf mountain-mahogany has soil-enriching attributes as noted by Lepper and Fleschner (1977).

Curlleaf mountain-mahogany communities appear to be stable or "climax" in nature. Rates of succession are considered to be extremely slow and dependent upon habitat factors relating to storage of soil moisture and to soil development processes, which are also slow in these xeric environments. On site 17, however, white fir had a cover value of 40%. The white fir trees were taller than curlleaf mountain-mahogany (site 17 average height 4.7 m [15.5 ft]), but with time the white fir will

likely shade out the shorter curlleaf mountain-mahogany plants. Another problem would be snow loads falling from the white fir trees and breaking limbs in the shorter and less flexible curlleaf mountain-mahogany. Because white fir occurred on only 2 of the 19 sites sampled, displacement of curlleaf mountain-mahogany by white fir is not thought to be a common occurrence in Utah. Site 17 was the only area sampled that had clay-loam soil, which may account for the response of fir there.

Dealy (1975) thought that the survival of curlleaf mountain-mahogany communities was dependent on fire-resistant rocky sites. Trees on such sites were larger and older than those on nearby nonrocky sites. These trees also provided seed if fire destroyed the non-rocky portion of the community. Dealy's opinion was based on finding charred trees and charcoal bits on nonrocky study areas. Scheldt (1969) observed similar patterns in areas in southern Idaho. We also observed that the larger trees occurred on the most rocky areas; the younger trees occurred on nearby areas of gentler slope and less rocky soils. We found no evidence of fire, however, on any of the study sites in Utah.

The fact that curlleaf mountain-mahogany produces good seed crops at very irregular intervals and is difficult to establish because its seedlings are sensitive to drought and frost (Plummer et al. 1968, Dealy 1975) may explain its common stand characteristics. Once a few trees are established, the "pioneering" individuals usually grow to large size before conditions for germination and growth of seedlings are met. Moreover, seedlings must compete with other established plant species. Rocky sites would offer less competition during establishment.

The distribution of curlleaf mountain-mahogany communities is not expected to change significantly in the future. The community type appears to be physiologically and morphologically adapted to a narrow elevation and/or moisture range of about 2000–3000 m in Utah. At higher elevations the exclusion of *C. ledifolius* from most areas is likely determined by competition with conifers and other plant species, which are more competitive for sunlight and moisture. Curlleaf mountain-mahogany can avoid competition by growing on ridges, canyon ledges, or high plateaus with poor soil development



where the conifers do not establish well. The lower altitudinal distribution patterns are most likely determined by lack of competitive ability on sites where soils are deeper and where mountain brush and pinyon-juniper do well.

Curlleaf mountain-mahogany communities are important because they grow in habitats where few other desirable woody plants will, and thus they provide plant cover for stabilizing otherwise unstable systems. Also, in their young stages these communities provide valuable forage for big game; later, as the communities age, they supply much-needed shelter in winter where environmental extremes predominate. More information is needed on ecological significance of curlleaf mountain-mahogany's soil-enriching attributes and possible effects on associated plant species.

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## SITE CHARACTERISTICS AND HABITAT REQUIREMENTS OF THE ENDANGERED DWARF BEAR-CLAW POPPY (*ARCTOMECON HUMILIS* COVILLE, PAPAVERACEAE)

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**ABSTRACT.**—*Arctomecon humilis* Cov. is a narrow endemic, confined to gypsiferous substrates derived from the Shinarump Member of the Moenkopi Formation in southwestern Utah. The characteristics of seven *A. humilis* sites were studied to define habitat requirements of the species. Both physical and biotic aspects of the habitat were analyzed; geology, soil chemistry, and physical properties, as well as vascular and nonvascular plant communities, were studied. Chemical and physical properties of these soils vary considerably from those supporting adjacent desert-shrub communities. The dominant vascular species on *A. humilis* sites are shadscale and Mormon tea. It was found that *A. humilis* occurred in portions of the habitat where shrubs were relatively less dense. A soil-surface, cryptogamic community contributed 84% or more of the total living cover on sites that supported *A. humilis*. Species composition of the cryptogamic community was highly similar among sites. Likewise, composition of the cryptogamic cover was similar when random samples were compared with samples centered on *A. humilis* plants. The Purgatory Flat site, which does not support the poppy, seems inseparable from *A. humilis* sites in respect to soil characteristics and composition of the associated plant cover. There is reason to believe an *A. humilis* population could be established at the Purgatory Flat site.

**Key words:** *Arctomecon humilis*, dwarf bear-claw poppy, habitat characteristics, gypsophily.

The dwarf bear-claw poppy (*Arctomecon humilis*) is a perennial herb endemic to gypsum soils of Washington County, Utah (Atwood 1977). It presently occupies an archipelago of isolated sites to the south, west, and east of St. George, all of which are within 8–10 km of the city limits. *A. humilis* is confined to substrates derived from outcrops of certain members of the Moenkopi Formation (USFWS 1985). No detailed discussions of the habitat requirements or general ecology of this species have previously appeared in the literature.

During the last several decades, the development of housing in the St. George–Bloomington area and the construction of Interstate 15 and associated road maintenance facilities have eliminated much of the plant's habitat. Off-road vehicle (ORV) traffic and mineral assessment work on gypsum claims immediately threaten remaining habitat. Off-road vehicles cause excessive erosion and loss of viable *A. humilis* seed stored in the surface soil (Nelson and Harper 1991). Continued development and expansion in the St. George area will undoubtedly result in continued

encroachment upon habitat now occupied by the species.

In 1979 the U.S. Fish and Wildlife Service issued a final rule statement declaring *A. humilis* an endangered species (USFWS 1979). Critical habitat was not designated in that ruling. Since 1979, several hundred acres of habitat have been closed to ORV use by the U.S. Bureau of Land Management (USBLM 1987) and the state of Utah, but difficulties in posting and enforcing these closures have resulted in almost no change in patterns of use on habitat occupied by the species. In fact, photographs taken at permanent photo points show an increase in evidence of ORV use on some of these sites over the period 1987–1990. While the direct effects of ORV and mineral exploration on living plants are not always extensive, soil erosion initiated by ORV traffic progressively destroys the limited habitat to which the species is intimately tied. Erosion also results in loss of seed from the soil seed bank. Since the species is short lived (up to perhaps six years), maintenance of viable populations depends upon regular establishment of plants from the seed bank.

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It is the purpose of this paper to define the habitat requirements of this species.

#### STUDY AREA

Approximately two-thirds of the habitat occupied by *A. humilis* is on federal land managed by the U.S. Bureau of Land Management (BLM). One-third is owned by the state of Utah and managed by the Utah Department of State Lands and Forestry. The seven poppy sites considered in this paper are managed by the state or by BLM.

In nearly all cases the species is confined to low gypsum hills typically found at the base of red cliffs. The sites are often underlain by similar red beds (see below). The plant occurs occasionally on red gypsum-rich soils but is more typically found on white-gray gypsiferous soils. The white gypsum substrate is almost always associated with a heavy cover of cryptogamic plants (i.e., lichens, mosses, blue-green algae) except where natural erosion and ORV travel have destroyed that cover.

Areas surrounding habitat occupied by the poppy support creosote bush (*Larrea tridentata* [DC.] Cov.) communities. Creosote bush and many of its associates are intolerant of gypsum (Meyer 1986) and are essentially absent from the poppy sites. The gypsum sites support a sparse shrub community that is dominated by burrobrush (*Hymenoclea salsola* T. & G.) and shadscale (*Atriplex confertifolia* [Torr. & Frem.] Wats.). At one site (Beehive Dome) the poppy occurs with the endangered gypsum cactus (*Pediocactus sileri* [Engelm.] L. Benson). Desert tortoises (*Gopherus agassizii* Cooper) have been observed among poppy plants at Red Bluff, but there is no evidence that the tortoises utilize *A. humilis*.

In addition to the seven poppy sites studied, we have sampled another site, Purgatory Flat, which does not support a poppy population. That site is included in the study because it is visually and chemically similar to sites occupied by the species and lies within the range of elevation of those sites. The Purgatory Flat site is only 8 km from existing populations of *A. humilis* at Shinob Kibe Dome near Washington, Utah. The gypsum hills at Purgatory Flat cover a large area extending south from Quail Creek Reservoir for 2.5–3 km. Portions of this area could be used if

attempts to establish additional populations of *A. humilis* are ever made.

St. George receives an average of 201 mm of precipitation annually (Brough et al. 1987). Most rainfall occurs during the winter months, but summer (June–September) convective storms contribute about one-fourth of the annual total. Year-to-year variation in total annual precipitation is considerable. The coefficient of variation for total annual precipitation over the past 30 years is 33.2%. A "Walter Diagram" for the St. George weather station (Fig. 1) shows the relationship between annual patterns of precipitation and temperature (Walter 1973). During the winter months, temperatures are low enough and precipitation great enough that soils can accumulate some moisture (striped area in Fig. 1). Warmer temperatures during the spring and summer months create a water deficit, since evaporation exceeds precipitation and moisture is only briefly available to plants (stippled area). Rosettes of *A. humilis* remain green throughout the year and can take advantage of available moisture at any time.

#### METHODS

During 1987 soil was collected at seven *A. humilis* sites: Red Bluff, Price City Hills, White Dome, Shinob Kibe Dome, Boomer Hill, Beehive Dome and Warner Ridge. (The name of the buttelike landform that appears as "Shinob Kibe Dome" on U.S. Geological Survey maps is reported by Gregory [1950] to have been derived from the Piute words *Shinob* [Great Spirit] and *kaib* [mountain]; Gregory considers the name of the geologic member, "Shnabkaib," to be a misspelling of the Piute name.) Soil was also collected at two sites at Purgatory Flat (just below the dike on the southern shore of Quail Creek Reservoir and south of U.S. Highway 17). Soil samples were taken with a 2.5-cm-diameter tube inserted to a depth of 15 cm. A minimum of six samples was collected at each site, the number collected depending upon the size and apparent heterogeneity of the site. Soils at most sites ranged from red, clay-rich to white, purely gypsiferous substrates. Both red and white substrate types were sampled if the poppy occurred on both. Subsamples from each site were combined for analytical purposes, and soils were analyzed by the Brigham

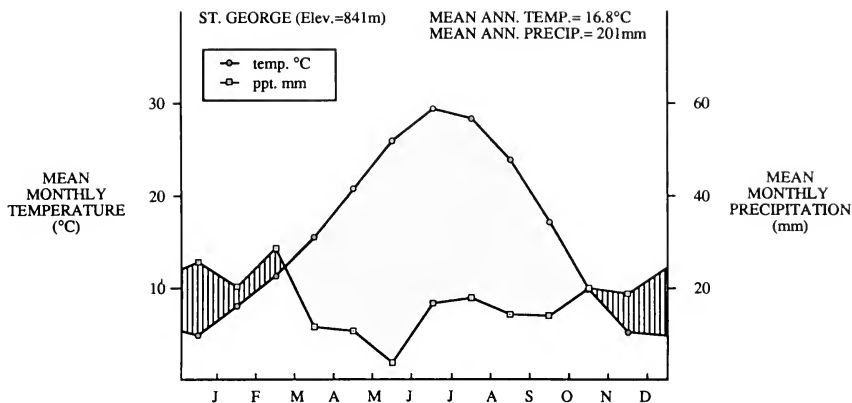


Fig. 1. "Walter Diagram" showing the relationship between average monthly precipitation (mm), along with average monthly temperature (°C) and mean annual temperature and precipitation, for the St. George, Utah, weather station. The stippled area represents a period of water deficit, when evaporation exceeds precipitation and moisture is only briefly available to plants; the striped area is a period when soils may accumulate water.

Young University Soil Laboratory, Department of Agronomy and Horticulture.

Samples were analyzed for concentrations of nine biogenic elements (P, Ca, Mg, K, Na, Zn, Fe, Mn, Cu), pH, electrical conductivity, cation exchange capacity, and linear extensibility (a quantification of a soil's tendency to shrink on drying). Micronutrients (Zn, Cu, Fe, and Mn) were extracted from soils with DPTA (diethylenetriamine-penta-acetic acid). Exchangeable calcium, magnesium, potassium, and sodium were extracted with 1.0 N neutral ammonium acetate. Phosphorus was extracted using 0.5 M sodium-bicarbonate. Individual ion concentrations were determined using a Perkin-Elmer Model 5000 atomic absorption spectrophotometer. Soil reaction was measured with a glass electrode pH meter on saturated soil pastes, and electrical conductivity of the saturated soil paste was measured using a standard wheatstone bridge (U.S. Salinity Laboratory Staff 1954). Cation exchange capacity (CEC) was determined by mass action using a 1.0 normal sodium acetate solution, washing away excess salts with distilled water, and displacing adsorbed sodium with ammonium acetate (Chapman 1965). Linear extensibility was estimated by oven-drying standard diameter cylinders of saturated soil paste for 24 hours and determining percentage change in length.

Results for the preceding suite of soil variables at each of the eight sites were subjected to cluster analysis (Sneath and Sokal 1973) using a program from the Ecology Program Library (W. E. Evenson and J. D. Brotherson, Brigham Young University, Provo, Utah). The values for each parameter at all sites were relativized before being entered in the program (i.e., the largest value for each variable was taken as 100% and all other values were expressed as a percentage of that maximum value). The program computes an index of similarity for all possible site pairs using the formula  $S. I. = [\Sigma(\text{minimum values for any attribute for the two sites}) / \Sigma(\text{maximum values for any attribute for the two sites})] \times 100$  (Ruzicka 1958), where "min" or "max" represents the smallest or largest of the values for each characteristic compared in the two stands.

In 1988 additional soil samples were collected at Beehive Dome, Price City Hills, Red Bluff, and Purgatory Flat. These soil samples were taken as described above. Contents of gypsum, calcium carbonate, sand, skeletal material, and water content at -15 bars matric potential were determined. Percent skeletal material was determined from the weight of the total sample retained on a 2-mm sieve. Percent sand was determined from the weight of material passing a 2-mm

sieve (No. 10 mesh) but retained on a 0.05-mm sieve (No. 275 mesh) and is reported as the percentage of the soil fraction less than 2 mm. Alkaline earth carbonates were determined by acid neutralization procedures (U.S. Salinity Laboratory Staff 1954). Gypsum content was determined with a loss-by-weight procedure by drying the soil at 45 C and 105 C, the difference in weight representing the loss of water incorporated into crystals of gypsum (Nelson 1982). Gypsum and calcium carbonate were measured for entire samples, which were ground prior to analysis. Water content was measured across a 15-bar pressure membrane (Richards 1965).

Vegetation was sampled during 1988 at Red Bluff, Price City Hills, and Purgatory Flats. Shrub density and cover, herb cover, and cryptogamic cover were measured along randomly placed 100-m transects. Shrub density was measured using the point-centered quarter method with distance measures taken from points spaced at 10-m intervals along the transect. Two canopy diameter measurements, taken at right angles to each other, were recorded for each shrub included in the sample. Shrub density was computed from the point-to-plant center data (Cottam and Curtis 1956). Shrub cover is based on canopy area of individuals and shrub density data. A nested frequency quadrat frame (Smith et al. 1987) was centered on each of the same points used for the point-quarter sampling and used to evaluate relative frequency and percent cover for cryptogamic species (lichens and mosses), vascular plants, and nonliving cover. At the two poppy sites where vegetation was sampled, Red Bluff and Price City Hills, these procedures were repeated but sampling was centered on the *A. humilis* plant nearest the 10-m point on the transect rather than on the transect line itself. Plant-centered versus random-point locations made it possible to test the hypothesis that the vegetational environment around *A. humilis* plants has a lower shrub density than the general habitat.

## RESULTS

### Physical Environment

*A. humilis* was found only on gypsic outcrops of the Moenkopi Formation of Early Triassic age (Fig. 2). The poppy has been reported to be confined to the upper three

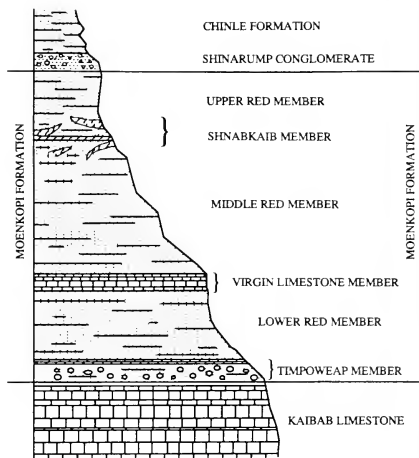


Fig. 2. Diagram showing the relative positions of geologic members of the Moenkopi Formation and adjoining strata in the vicinity of St. George, Utah. (From: R. K. Gierisch 1981. Observations and comments on *Pediocactus sileri* in Arizona and Utah. Desert Plants 3: 9-25.)

members: the Upper Red, Shnabkaib, and Middle Red (USFWS 1985). The majority of the populations occur almost exclusively on the Shnabkaib Member (W. Kenneth Hamblin, personal communication). Shnabkaib outcrops also occur in the northwest portion of Purgatory Flat, at the base of red cliffs. The gypsum hills across much of the Purgatory Flat area consist of alluvial sediments derived from the Shnabkaib.

In Washington County the Shnabkaib Member varies from 80 to 225 m in thickness and consists of white, pink, and light red gypsiferous shale and gypsum (Cook 1960). It is easily recognized by its candy-stripe appearance. In many places surrounding St. George it forms low hills at the bases of red cliffs of the Upper Red Member. These Upper Red cliffs are capped by the Shinarump Conglomerate. A large area of Shnabkaib is bisected by Interstate 15, and an unknown number of acres lie under housing developments in the Bloomington area of St. George and in older sections of St. George itself. The White Hills area west of Bloomington is the largest contiguous portion of exposed Shnabkaib in the vicinity.

Soils on *A. humilis* sites consist of little-altered parent material and are soils only in

the broadest definition of the word. There is no obvious horization in these substrates, though the uppermost portions would surely be somewhat enriched by additions from the cryptogamic crust and very locally (e.g., at the base of shrubs) by organic amendments from vascular plants. The influence of cryptogams may extend downward into the solum for only a few millimeters. Little organic matter is added to the soil annually, due to sparse vegetative cover. Minimal input of organic matter combined with a dynamic soil surface resulting from dissolution and reformation of gypsum crystals appears to preclude horizon development. The soil survey report for Washington County (USDA 1977) refers to these areas as "badlands" and does not further describe or classify the soils.

Results of soil analyses are shown in Table 1. The heterogeneity of these sites, as discussed above, is reflected in physical and chemical analyses. Within-site variation was considerable (with coefficients of variation exceeding 20%) for all parameters except calcium, electrical conductivity, and pH. In most cases within-site variation for a given variable was as great as that between sites. No site contributed more than one-fourth of the extreme high or extreme low mean values for the various parameters, suggesting that no site, including Purgatory Flat, can be considered chemically distinct from the others. Soils from the Purgatory Flat site show fewer extreme values for the variables considered than do soils from some poppy sites. Furthermore, no raw values for the Purgatory Flat site fall outside the range of values for corresponding variables from poppy sites. The similarity of Purgatory Flat soils to soils at poppy sites is also demonstrated through cluster analysis (Fig. 3), performed as described in Methods.

All soils sampled are slightly basic, with pH in the range of 7.2–7.5, and are highly gypsiferous, with gypsum contents ranging from 27 to 51%. Calcium carbonate content, which ranges from 15 to 24%, is also high. Rasmussen and Brotherson (1986) reported data on soils from desert shrub communities of Washington County that occur adjacent to *A. humilis* habitat. Mean values for pH and CEC presented here for *A. humilis* sites are slightly lower than those reported for the desert shrub soils, but they are within the range of one standard deviation of their mean.

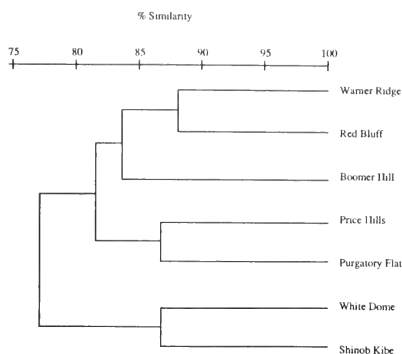


Fig. 3. Dendrogram resulting from clustering of six *A. humilis* sites and one potential *A. humilis* site (Purgatory Flat) for the following soil attributes: P, Ca, Mg, K, Na, Zn, Fe, Mn, Cu, cation exchange capacity, pH, electrical conductivity, and shrinkage upon drying (coefficient of linear extensibility).

Concentrations of magnesium and potassium are 50% lower on the gypsum soils, while levels of phosphorus and zinc are not different. The most striking differences are between concentrations of calcium, copper, and iron. Levels of calcium and copper are 10 times greater in *A. humilis* soils, while iron concentrations are the same magnitude lower. Obviously, these disparities have not interfered with the growth of *A. humilis*, and there is little evidence to suggest that such abnormal values are required for its existence. Meyer (1986) concludes that the likelihood of chemical factors controlling species composition on gypsum soils is minimal, and that the degree of endemism on gypsum soil is due to physical properties of the soil that affect available moisture for plant growth.

Soil texture is not reported here because of difficulties in textural determination created by properties of these soils: high concentrations of salt cause fine particles to become flocculated, thus rendering hydrometric procedures useless, and gypsum crystals complicate particle size determination through sieving. It is likely that much of the sand-size component, as measured here by sieving, consists of gypsum. The percentage of sand-size particles in the soil fraction smaller than 2 mm ranges from 14 to 29%, leaving three-fourths of the weight of the <2 mm material to

TABLE 1. Mean values for selected chemical and physical soil parameters at seven *A. humilis* sites and one potential *A. humilis* site (Purgatory Flat). Standard error is shown in parentheses. Elemental analyses were not run for the Beehive Dome site. Values are not available for the last five parameters at Boomer Hill, Shinob Kibe, Warner Ridge, and White Dome.

	Beehive Dome	Boomer Hill	Price Hills	Red Bluff	Shinob Kibe	Warner Ridge	White Dome	Purgatory Flat
Nutrients (ppm)								
P	—	17.0 (5.89)	33.7 (1.43)	22.9 (2.76)	19.4 (5.14)	5.9 (0.62)	8.8 (1.71)	33.8 (5.34)
Ca (ppm $\times 10^{-4}$ )	—	3.6 (0.19)	3.7 (0.22)	4.0 (0.13)	4.2 (0.11)	4.0 (0.10)	3.9 (0.09)	4.1 (0.07)
Mg	—	97.6 (7.74)	76.3 (3.82)	73.9 (4.87)	60.8 (6.79)	81.2 (6.25)	57.6 (5.12)	74.3 (5.14)
K	—	105.9 (9.24)	82.6 (4.63)	74.1 (4.71)	46.3 (9.07)	78.6 (6.79)	42.9 (10.1)	74.6 (11.53)
Na	—	15.2 (1.39)	15.3 (0.63)	13.7 (0.70)	14.2 (1.37)	14.2 (0.57)	11.6 (0.43)	14.4 (0.85)
Zn	—	0.4 (0.02)	0.4 (0.03)	0.3 (0.02)	0.2 (0.02)	0.3 (0.03)	0.3 (0.04)	0.5 (0.22)
Fe	—	2.9 (0.12)	2.6 (0.25)	2.5 (0.15)	1.8 (0.06)	2.9 (0.19)	1.9 (0.11)	2.1 (0.19)
Mn	—	1.5 (0.08)	1.2 (0.03)	1.3 (0.08)	1.0 (0.15)	1.1 (0.16)	1.0 (0.10)	1.1 (0.17)
Cu	—	0.9 (0.07)	0.9 (0.04)	0.8 (0.10)	1.0 (0.35)	0.9 (0.10)	0.9 (0.10)	1.6 (0.73)
CEC <sup>1</sup>	—	9.6 (0.50)	7.4 (0.23)	8.2 (0.40)	6.0 (0.49)	7.7 (0.50)	5.5 (0.61)	7.4 (0.50)
pH	—	7.3 (0.07)	7.3 (0.06)	7.2 (0.05)	7.3 (0.10)	7.5 (0.03)	7.3 (0.06)	7.4 (0.05)
EC <sup>2</sup>	—	2.2 (0.06)	2.2 (0.10)	2.4 (0.05)	2.2 (0.05)	2.2 (0.03)	2.2 (0.06)	2.2 (0.05)
COLE <sup>3</sup>	—	1.3 (0.21)	0.8 (0.17)	1.0 (0.19)	0.7 (0.48)	1.0 (0.19)	0.4 (0.18)	0.9 (0.20)
%H <sub>2</sub> O - 15 bar	11.4 (0.81)	—	8.2 (2.26)	11.8 (2.42)	—	—	—	14.6 (1.18)
CaCO <sub>3</sub> (% by wt.)	15.4 (0.52)	—	24.3 (0.09)	22.6 (1.85)	—	—	—	18.8 (2.31)
CaSO <sub>4</sub> (% by wt.)	32.7 (4.70)	—	27.3 (12.22)	39.3 (15.38)	—	—	—	51.1 (5.36)
Sand (% of <2mm)	14.6 (2.71)	—	26.0 (5.19)	24.2 (8.99)	—	—	—	29.0 (4.39)
Skeletal (% of total)	14.3 (2.55)	—	18.1 (9.02)	16.9 (10.27)	—	—	—	9.0 (3.08)

<sup>1</sup>CEC = cation exchange capacity in meq per 100 g of soil

<sup>2</sup>EC = electrical conductivity in mmho/cm.

<sup>3</sup>COLE = coefficient of linear extensibility. 0 = shrinkage, 1 = <3% shrinkage, 2 = 3–6% shrinkage.

be contributed by silt- and clay-size particles. The large proportion of fine particles is congruous with the prevalence of shales in the Shnabkaib and adjacent geologic members. Shrinkage of saturated soil pastes upon drying (coefficient of linear extensibility) ranged from 0 to 6%, the higher values suggesting that the finer materials in some of the soils include expanding clays.

#### Biotic Associates

Total living cover on the three sites sampled ranged from 37 to 59% (Table 2). Differences between values measured for that variable at random points and at *A. humilis*-centered points are small and probably not significant. (Total cover values could not be tested for significance because data for shrubs were collected by a method different



TABLE 2. Percent absolute living cover and percent relative cover contributed by groups of nonvascular and vascular plants for general habitats and for habitats at *A. humilis*-centered sampling points at two *A. humilis* sites (Price City Hills and Red Bluff) and for the general habitat at one gypsiferous site on which an *A. humilis* population does not now exist (Purgatory Flat). Trace amounts are noted "T".

	Price City Hills		Red Bluff		Purgatory Flat
	Random points	<i>A. humilis</i> centered	Random points	<i>A. humilis</i> centered	(Potential <i>A. humilis</i> site)
Absolute living cover (%)	46.7	46.2	37.2	31.2	59.6
Relative cover (%)					
Nonvascular (total)	(93.7)	(96.0)	(84.0)	(92.1)	(88.1)
Lichens					
<i>Collema tenax</i>	70.9	64.9	61.6	58.0	65.6
<i>Psora decipiens</i>	17.4	28.4	19.0	32.0	15.7
Other	5.4	2.7	1.1	2.0	6.8
Moss	T	T	2.2	T	1.2
Vascular (total)	(6.3)	(4.0)	(16.0)	(7.9)	(11.9)
Grasses and forbs		1.6	1.1		1.9
Shrubs					
<i>Atriplex confertifolia</i>	1.6	0.4	4.3	1.9	3.2
<i>Ephedra torreyana</i>	2.2	1.4	4.5	4.2	3.5
<i>Hymenoclea salsola</i>	1.4	0.2	5.0	0.9	1.5
Other	1.1	0.6	1.0	1.2	1.8

from that used for nonvascular plants and forbs.)

Nonvascular plants contributed 84% or more of the total living cover at all sites (Table 2). Lichens were the most important component of the nonvascular plant cover and total living cover measured. Species composition and cover at the three sites and at both random and poppy-centered points were similar. The lichens, *Collema tenax* (Sw.) Ach. and *Psora decipiens* (Hedw.) Hoffm., were the most common species at all sites, the former accounting for 58–71% of the lichen cover, and the latter 16–32%. Grasses and forbs contribute little to the total cover on these sites and in two cases were not encountered in sampling (Table 2). Many species of grasses and forbs on these sites are annuals and are present only during a part of the year. Red brome (*Bromus rubens* L.), an introduced species, is the most common annual on these sites, through it was not frequently encountered in quadrats. It grows in abundance only at the base of shrubs and is rarely associated with *A. humilis* plants.

Shrub densities measured at random points and at *A. humilis*-centered points at Price City Hills and Red Bluff, and at random points at Purgatory Flat, are reported in Table 3. Differences among shrub densities were tested for significance using a least significant difference method at the alpha = .05 level

(Steele and Torrie 1960). Analysis was based on point-to-plant distances. Shrub density at the Purgatory Flat site was not different from that measured at random points at Red Bluff and *A. humilis*-centered points at Price City Hills. Densities measured from random points and from *A. humilis*-centered points differed significantly at the latter two sites, though the density at random points at Price City Hills was not significantly different from the density at *A. humilis* points at Red Bluff. It thus appears that within each habitat, the poppy occupies portions of the habitat where shrubs are relatively less dense.

Shrub species composition was similar at all three sites with the exception of the presence of bursage (*Ambrosia dumosa* [Gray] Payne) at Purgatory Flat. This species contributed 15% of shrub individuals at that site. At Price City Hills, *Lepidium fremontii* Wats., a suffrutescent subshrub, had a relative density of 60%, but only 5–6% at other sites. While *Lepidium* was common on the Price City Hills site, individual plants were small (mean area of 73 cm<sup>2</sup>) and contributed less than 5% of the total living cover. All three sites are dominated by shadscale and Mormon tea (*Ephedra torreyana* Wats.), while adjacent areas are dominated by creosote bush and blackbrush (*Coleogyne ramosissima* Torr.) (Rasmussen and Brotherson 1986).

TABLE 3. Total shrub density for the general habitat and for *A. humilis*-centered sampling determined with the point-quarter method at two *A. humilis* sites (Price City Hills and Red Bluff) and for the general habitat at one non-*A. humilis* site (Purgatory Flat). Relative density for major shrub species is based on the sample taken with the quarter method. Shrub density differences among sites were tested for statistical significance: means followed by the same letter in subscript do not differ significantly.

	Price City Hills		Red Bluff		Purgatory Flat
	Random points	<i>A. humilis</i> centered	Random points	<i>A. humilis</i> centered	(Potential <i>A. humilis</i> site)
Total shrub density (no./ha)	2365 <sub>c</sub>	1286 <sub>b</sub>	1515 <sub>b</sub>	636 <sub>a</sub>	1759 <sub>b</sub>
Relative density (%)					
<i>Ambrosia dumosa</i>					15.0
<i>Atriplex confertifolia</i>	25.0	18.9	47.5	48.8	45.6
<i>Ephedra torreyana</i>	8.8	8.8	15.8	30.0	11.3
<i>Hymenoclea salsola</i>	5.0	3.8	28.3	11.3	18.1
<i>Larrea tridentata</i>					0.6
<i>Lepidium fremontii</i>	60.0	66.3	6.7	5.0	5.0
<i>Lycium andersonii</i>	1.3	2.5		5.0	0.6
<i>Psoralea fremontii</i>			1.7		2.5
<i>Stanleya pinnata</i>					1.3

## DISCUSSION

*A. humilis* sites studied are similar with regard to physical and biological parameters. All occur on the same geologic member within an elevational range of 750–1050 m. Each site is heterogeneous with regard to the soil parameters measured, but no site appears to be exceptionally different from all others as might be predicted, since all sites are on a common parent material. Species composition of the vascular and nonvascular plant communities studied was similar for all sites. All gypsiferous sites were dominated by shadscale and Mormon tea. Creosote bush dominated areas immediately adjacent. Within its habitat *A. humilis* was found to occupy areas that have a lower shrub density relative to the general habitat. No difference in cryptogamic plant cover could be detected for areas surrounding *A. humilis* plants relative to the general habitat.

The Purgatory Flat site does not appear to differ significantly from *A. humilis* habitats for any of the parameters studied. It seems likely that *A. humilis* could survive and reproduce on in-place outcrops of the Shnabkaib at this site. Distance from St. George makes this site less likely to be threatened by development; and intensity of ORV traffic, as evidenced by tracks and trails, is considerably less than on most *A. humilis* sites. The outcrops of Shnabkaib along the north end of the basin lie in a narrow strip between state highways 9 and 17 and cliffs formed by the Upper Red, making it possible to protect the site by fencing

along two sides only. For purposes of habitat protection, portions of the Purgatory Flat area should receive status similar to *A. humilis* sites.

*A. humilis* is strictly associated with a unique and limited habitat, and maintenance of viable populations of the species requires the protection of this habitat, much of which is impacted by cultural disturbances. All of the sites studied show damage to the habitat, particularly to the cryptogamic plant cover, and to *A. humilis* plants directly. Most damage is related to ORV use. Recent surface mineral assessment work at two sites has resulted in the disturbance of soil surfaces and the destruction of plants. The rapid growth of St. George and associated new developments poses inevitable threats. Although critical habitat was not defined for the species in the 1979 mandate that gave it protection under the Endangered Species Act, continuing habitat degradation over the last 10 years suggests that such designation is appropriate. If this species is to be preserved, portions of the habitat must be protected from development and ORV traffic. Establishment of additional populations on unoccupied outcrops of suitable habitat should be attempted while genetic diversity is still available.

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## BROMUS INVASIONS ON THE NEVADA TEST SITE: PRESENT STATUS OF *B. RUBENS* AND *B. TECTORUM* WITH NOTES ON THEIR RELATIONSHIP TO DISTURBANCE AND ALTITUDE

Richard Hunter<sup>1</sup>

**ABSTRACT.**—*Bromus rubens* and *Bromus tectorum* are now nearly ubiquitous components of the Nevada Test Site (NTS) flora. Introduced to the western United States in the late 1800s, they spread through the Mojave and Great Basin deserts in the early twentieth century. Since quantitative studies began on the NTS in 1957, *Bromus* spp. have greatly increased in frequency and density. By 1988 both species occurred in many places at densities exceeding 1000 individuals per square meter. They may significantly increase flammability of the vegetation and reduce success of native ephemeral species.

**Key words:** *Bromus rubens*, *Bromus tectorum*, Nevada Test Site, introduced species, fire propagation, fire recovery.

In the roughly 150 years of American settlement of the western United States approximately 20 species of *Bromus* have been introduced (Munz 1968). Of these species, two, *Bromus tectorum* and *B. rubens*, have dramatically spread over rangelands. In the Great Basin Desert *B. tectorum* has had major impacts on rangelands and agricultural yields (e.g., Morrow 1984), and in parts of California and the Mojave Desert *B. rubens* has come to dominate the annual plant floras.

The Nevada Test Site (NTS) is a 1350-square-mile enclave straddling the boundaries and transition zone between the Mojave and Great Basin deserts (Fig. 1). Eight *Bromus* species occur on the NTS, six of them introduced (Beatley 1976). Both *B. rubens* and *B. tectorum* are now widespread and significantly affect the NTS ecology. This paper is an attempt to document the present status of these two species and provide information on the nature of their increase in abundance.

### History of *Bromus* Introductions

#### *Bromus rubens*

Frenkel (1970) considered *B. rubens* to have been introduced during the Mexican occupation of California between 1825 and 1848, and S. B. Parish called an 1889 roadside specimen from San Bernardino County, California,

“a recent introduction” (California Academy of Science Herbarium). In the Mojave Desert it was not seen on an 1891 expedition to Death Valley (Coville 1893). M. E. Jones first collected *B. rubens* in 1907 at Searchlight, Nevada (Rancho Santa Ana Herbarium). Mrs. F. P. Morris collected it at Mojave, California, in 1917 (California Academy of Science Herbarium). V. Duran, in 1933, called it a “common grass between Mojave and Palmdale along roadsides and on cleared land” (Intermountain Herbarium, Utah State University). On the eastern edge of the Mojave, E. Snow collected *B. rubens* in 1931 near St. George, Utah (University of California, Davis Herbarium, Crampton Collection).

Near the NTS, I. W. Clokey (1951) collected plants in the Charleston Mountains from 1937 through 1941. He collected *B. rubens* from only one location, at 1550 m (5085 ft) in a disturbed area of the “juniper belt.” The distribution on that specimen label was noted as “roadsides and waste places.” O. V. Deming collected specimens of *B. rubens* on the Desert National Wildlife Range (directly east of the NTS) in 1946 (University of Nevada, Las Vegas Herbarium).

It appears, therefore, that *B. rubens* invaded the Mojave Desert during the 1920s, spreading first to disturbed areas. It was not common, however, until after 1950. By 1963

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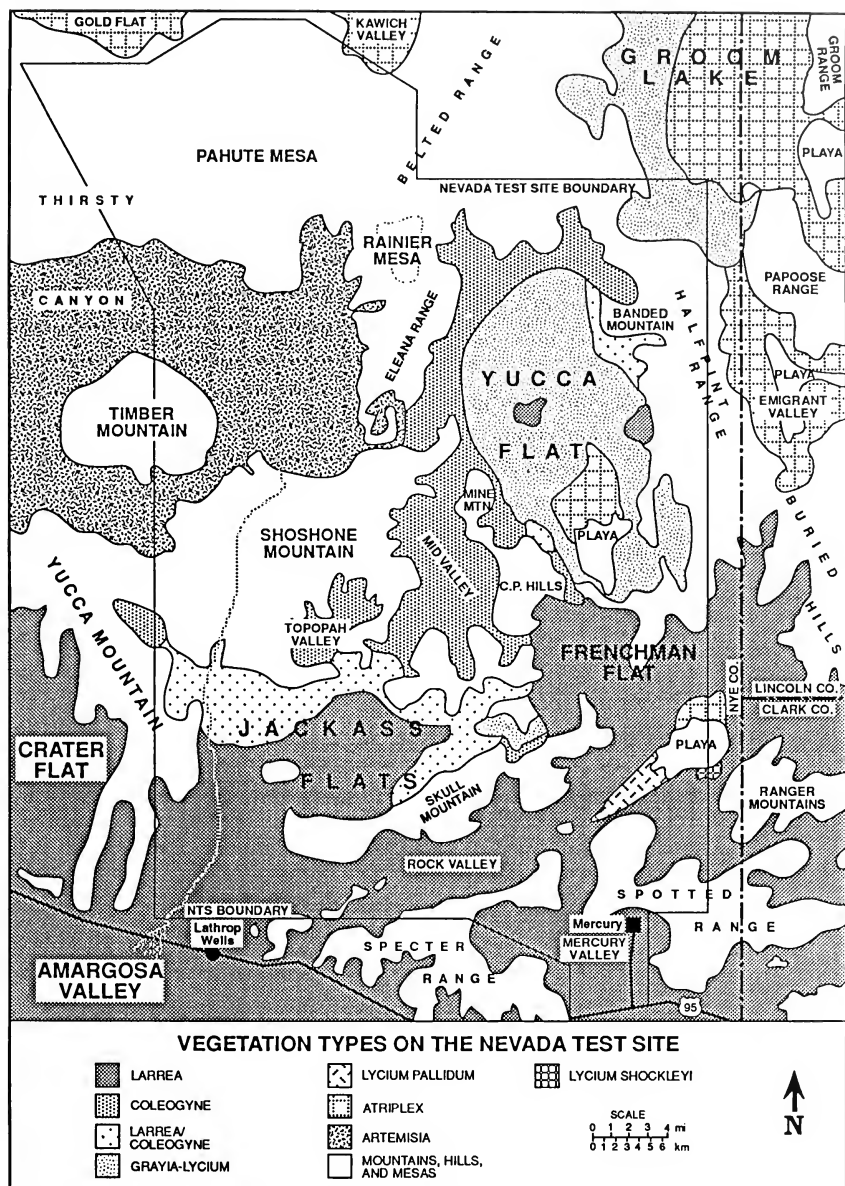


Fig. 1. Major landforms and vegetative communities on the NTS as determined by Beatley (O'Farrell 1976).

it was abundant on the NTS at elevations of 1219–1524 meters (4000–5000 feet), though infrequent in the *Larrea tridentata* associations below that altitude (Beatley 1966).

### *Bromus tectorum*

The spread of *B. tectorum* has been described by several other authors and occurred primarily at higher altitudes and latitudes than that of *B. rubens*. It was first recognized in 1861 (Morrow and Stahlman 1984, citing Hitchcock 1950). Mack (1981) described the invasion of *B. tectorum* into western North America, a process that he considered completed by roughly 1928. Yensen (1981) and Morrow and Stahlman (1984) also reviewed this process.

Mojave Desert collections of *Bromus tectorum* were rare before 1950. Clokey (1951) cited six collections of *B. tectorum* in the Charleston Mountains during the late 1930s. F. W. Gould collected it in 1942 as a roadside weed in St. George, Utah, and P. Dalley (1943) and O. V. Deming (1946) collected *B. tectorum* on the Desert National Wildlife Range (University of Nevada, Las Vegas herbarium). Beatley (1966) reported it on the NTS in disturbed patches above 1524 m (5000 ft).

### METHODS

Plots for studies since 1987 were selected to be representative of either a particular disturbance or an undisturbed area nearby. Some plots were considered pristine, chosen specifically for lack of disturbance. *Bromus* densities were not considered when selecting a site. Altitudes of sampled locations were determined from United States Geological Survey 7.5-minute topographical maps.

Twenty .025-m<sup>2</sup> randomly placed quadrats within 1000-m<sup>2</sup> plots were used to monitor ephemeral plants (1987–1990). Monitoring also included harvesting of all annual plants within each quadrat. New quadrat locations were selected within approximately the same 1000 m<sup>2</sup> every year. Harvested plants were oven-dried at 66 C for three days, then equilibrated with room air before weighing.

### RESULTS

#### Present Distribution

The distributions of the two *Bromus* species

with respect to altitude and disturbance are shown in Table 1. *B. rubens* was present at all but one sampled location (Rainier Mesa, 2286 m [7500 ft]). It was present at less than two plants per square meter at only two locations, Jackass Flats and Pahute Mesa. The former was an area of deep, sandy soil at 945 m (3100 ft), near the lowest altitude on the NTS, and the latter was in an established *Artemisia nova* community at 1890 m (6200 ft), above the normal distribution zone for *B. rubens*. It was therefore essentially ubiquitous on the NTS below 1524 m (5000 ft). At four locations sampled in both 1987 and 1988, population densities increased an average of threefold ( $3.38 \pm 0.89$ , sem), indicating both good reproduction in 1987 and good germination in 1988 (Table 1). The median density in 1988 was  $362 \pm 84$  plants per square meter ( $\pm$  sem; 19 sites). The highest densities were found on areas where soils were softened and shrubs killed by gopher and small mammal activities, but several undisturbed locations had densities over 1000/m<sup>2</sup>.

The populations of *B. rubens* were heavily infested with a smut (*Ustilago bullata* Berkeley) fungus. In 1987 the smut was present on 0–36% of *Bromus rubens* plants on 5 sites; in 1988 it ranged from 0% to 43% on 17 sites, with an average ( $\pm$  sem) of  $15 \pm 3\%$ . The smutted plants produced no viable seed. Presumably this disease significantly reduced seed production. However, smut was noted by others in early populations (e.g., A. A. Beetle 1941, University of California, Berkeley Herbarium), and it apparently did not prevent increases in density.

In the early 1980s *Bromus tectorum* became noticeably common below 1524 m (5000 ft). In Yucca Flat on some of the ground zeroes (GZs) are areas denuded by nuclear bomb blasts in the 1950s and early 1960s) it was seen in apparent near-monoculture patches surrounded by *B. rubens* monocultures. In Mercury township (the NTS base camp) it occurred in the vicinity of buildings and roads associated with *B. rubens*, while away from disturbance it was absent. In 1983 in the blast zone surrounding Sedan Crater, which resulted from a peaceful nuclear explosion excavation experiment, *B. rubens* was seen at all 12 sites on which perennials were measured, and *B. tectorum* was also present at 6 of those sites (Hunter and Romney, unpublished observations).

TABLE 1. Densities of *Bromus rubens* and *B. tectorum* ( $\text{m}^2 \pm \text{sem}$ ) in 1987 (\*) and 1988 in relation to disturbance and altitude (m).

Location	Disturbance	Altitude	<i>B. rubens</i>	<i>B. tectorum</i>
Jackass Flats	none	950	+	0
Jackass Flats	none	950	$16 \pm 14$	+
Frenchman Flat	gopher	960	$2644 \pm 716^*$	+
Frenchman Flat	none	975	$48 \pm 35^*$	0*
			$258 \pm 153$	$4 \pm 4$
Frenchman Flat	none	1000	$34 \pm 22$	0
Frenchman Flat	roadside	1000	$4 \pm 3$	0
West Mercury Valley	gopher	1040	$3550 \pm 366$	0
Rock Valley	none	1070	$754 \pm 298^*$	0*
			$2034 \pm 632$	+
Mercury town	none	1150	$352 \pm 120^*$	+
			$446 \pm 130$	$2 \pm 2$
Mercury town	shrubs removed	1150	$456 \pm 192^*$	+
			$1912 \pm 476$	$8 \pm 7$
East Yucca Flat	none	1240	$652 \pm 328$	+
Southwest Yucca Flat	none	1250	$1872 \pm 556$	$20 \pm 11$
West Yucca Flat	none	1280	$188 \pm 49$	$2 \pm 2$
West Yucca Flat	ground zero	1290	$1472 \pm 356$	$1884 \pm 396$
Southwest Yucca Flat	none	1300	$1803 \pm 474^*$	0
Southwest Yucca Flat	fire—1985	1300	$720 \pm 168^*$	+
North Yucca Flat	Sedan GZ	1325	$19 \pm 11$	$1155 \pm 431$
North Yucca Flat	Sedan GZ	1325	$324 \pm 154$	$2004 \pm 424$
North Yucca Flat	none	1325	$142 \pm 69$	$2 \pm 2$
Northwest Yucca Flat	none	1400	$658 \pm 344$	$4 \pm 4$
Northwest Yucca Flat	T2 GZ	1400	$774 \pm 169$	+
South Mid-valley	none	1463	$362 \pm 84$	$414 \pm 152$
South Mid-valley	fire—1986	1463	$114 \pm 37$	$3916 \pm 752$
Pahute Mesa	none	1900	+	+
Rainier Mesa	none	2300	0	0

*Bromus tectorum* densities in 1987–88 differed considerably from those of *B. rubens*. This species was absent or at densities  $< 2/\text{m}^2$  below 1219 m (4000 ft). Above that altitude it was present at  $> 1000/\text{m}^2$  on several burned and GZ areas. It was not dense on all disturbed sites above 1219 m, however, as seen on the 1985 fire area and T2 GZ (Table 1). Its distribution was therefore considerably patchier than that of *B. rubens*, and it was associated more strongly with disturbance.

Data on plant size from locations where the two species occurred together show that *Bromus tectorum* is the larger of the two species ( $p < .02$ ; Wilcoxon Signed Rank Test; Ostle 1963) and may therefore have a competitive advantage (Table 2). The vegetative and seed characteristics of the two species are very similar, and I would expect seed production to be similarly proportional to plant weight in both.

## DISCUSSION

A comparison of these recent data with those taken earlier demonstrates a significant

TABLE 2. Average weights per plant ( $\text{mg} \pm \text{sem}$ ) of *B. rubens* and *B. tectorum* when growing at the same location.

Site	<i>Bromus rubens</i>	<i>Bromus tectorum</i>
Disturbed		
Mid-valley	$26 \pm 11$	$33 \pm 7$
Yucca Flat—Sedan	$23 \pm 9$	$47 \pm 13$
Yucca Flat—Sedan	$9 \pm 2$	$19 \pm 6$
Yucca Flat—T1 GZ	$11 \pm 3$	$17 \pm 4$
Pristine		
Mid-valley	$11 \pm 1$	$20 \pm 2$
Yucca Flat—001a	$14 \pm 2$	$23 \pm 6$
Yucca Flat—001b	$16 \pm 2$	$38 \pm 2$

increase in both frequencies and densities over the past 30 years. The earliest data taken in association with the nuclear bomb testing program were from 1957 to 1959 (Shields and Rickard, unpublished reports). They reported cover data, which could not be directly compared to our density data. However, in three valleys (Yucca Flat, Frenchman Flat, and Jackass Flats; altitudes 945–1524 m) Shields and Rickard measured ephemeral plants at 41 plots and found *Bromus rubens* at only 22 of

them (54%). In 1987–88 I found *B. rubens* in those same three valleys at all 21 plots sampled (significantly different by chi square at  $p < .001$ ). Similarly, Beatley (1966) reported *B. rubens* at 8 of 18 plots in Yucca Flat in 1964, while I found it at all 11 sampled locations (significant at  $p < .01$ ). At the two sites where a direct comparison was reasonable, Beatley found 0.0, and 0.2 *B. rubens* per square meter in 1964, while I found  $1803 \pm 474$  and  $1434 \pm 304$  per square meter in 1987–88. At an undisturbed site near the Sedan GZ Martin (unpublished) found 0.6 *B. rubens* per square meter, while in 1988 at the same location I found  $142 \pm 69$ .

The most complete time series is for a small area in Rock Valley where records of Beatley, U.S. Desert Biome/International Biological Program researchers, and our studies are available covering 20 of the 26 years since 1962. Table 3 shows that there was an increase from fewer than 10 *B. rubens* per square meter in the 1960s and early 1970s to thousands per square meter in the late 1980s. This increase began in 1974, following the excellent growth year of 1973. Since then, years of good growth have resulted in a staircase amplification of *B. rubens* population density. At the same time the populations of native annuals fluctuated without any dramatic trends toward increased or decreased density (Table 3). In 1989 and 1990 drought prevented germination of ephemeral plant species.

Biomass data from U.S. International Biological Program Desert Biome studies and our results show trends similar to those on density (Table 4). That is, *B. rubens* greatly increased in biomass at the same time it increased in density, while biomass of native species was highly variable without demonstrating any trends. Proportionately, *Bromus* biomass increased from approximately 10% of ephemeral biomass to 97% between 1972 and 1988.

Differences in sampling techniques and areas sampled, coupled with a naturally high year-to-year variability in richness, prevented any significant diversity comparisons among data of Shields, Beatley, IBP/Desert Biome, and BECAMP studies. However, high *B. rubens* densities resulting from irrigation and fertilization treatments were associated with a decrease in species richness of native species (Hunter, in press).

TABLE 3. Densities of *Bromus rubens* (n/m<sup>2</sup>) and native species measured in several adjacent Rock Valley plots between 1963 and 1974.

Year	<i>Bromus rubens</i>	Natives
1963 <sup>1</sup>	5.0	10.0
1964 <sup>1</sup>	6.2	27.6
1965 <sup>1</sup>	2.2	2.4
1966 <sup>1</sup>	3.2	69.6
1967 <sup>1</sup>	3.6	7.0
1968 <sup>1</sup>	7.6	99.6
1969 <sup>1</sup>	14.0	109.8
1970 <sup>1</sup>	19.8	14.0
1971 <sup>1</sup>	0.2	2.0
1972 <sup>1</sup>	0.0	3.0
1973 <sup>3</sup>	0.4	118
1974 <sup>2</sup>	11.2	101
1975 <sup>2</sup>	13.2	216
1976 <sup>2</sup>	90.9	327
—	—	—
1983 <sup>4</sup>	89	108
1984 <sup>4</sup>	167	19
1985 <sup>4</sup>	156	111
1986	—	—
1987 <sup>5</sup>	754 $\pm$ 298	100 $\pm$ 22
1988 <sup>5</sup>	2034 $\pm$ 632	86 $\pm$ 33
1989 <sup>5</sup>	0 $\pm$ 0	0 $\pm$ 0
1990 <sup>5</sup>	16 $\pm$ 16	0 $\pm$ 0

<sup>1</sup>Beatley, unpublished

<sup>2</sup>Turner 1972–1976

<sup>3</sup>Turner and McBrayer 1974

<sup>4</sup>R. B. Hunter and K. B. Hunter, unpublished

<sup>5</sup>This paper

TABLE 4. Biomasses (g/m<sup>2</sup>) of *Bromus rubens* and native species in Rock Valley. Data for the 1970s are from Turner 1972–76, Turner and McBrayer 1974, and Turner, unpublished.

Year	<i>Bromus rubens</i>	Natives
1971 <sup>1</sup>	0.10	0.54
1972 <sup>1</sup>	0.04	0.40
1973 <sup>2</sup>	1.29	78.9
1974 <sup>1</sup>	0.83	1.50
1975 <sup>1</sup>	2.13	22.5
1976 <sup>3</sup>	3.25	12.0
—	—	—
1987	17.0	0.51
1988	34.0	0.9
1989	0.0	0.0
1990	0.0	0.0

### *Bromus tectorum*

Beatley (1966) described the status of *B. tectorum* as present only above 1524 m (5000 ft), largely in disturbed areas of *Artemisia tridentata*-dominated vegetation. This contrasts with my data (Table 1), which demonstrated a significant presence of *B. tectorum* throughout Yucca Flat, 1219–1524 m (4000–5000 ft) in the late 1980s.



The propensity of the *Bromus* species to carry fire has been frequently noted (e.g., Stewart and Hull 1949, Beatley 1966, Yensen 1981). The dead stems and litter persist for a year or two and serve to carry fire across bare areas between shrubs and trees. On the NTS this is true for both *B. rubens* and *B. tectorum*. On the NTS fires burned an estimated 38,000 acres between 1978 and 1987 (R. R. Gudeman, personal communication), in spite of active control efforts. The *Bromus* species were significantly present both in control and previously burned areas (Table 1), suggesting a role both in fire propagation and recovery of vegetation following fire.

The effects of the *Bromus* populations on native ephemerals were not clear. Table 4 shows no significant downward trend in native population densities. The native ephemerals behaved somewhat differently from *B. rubens*, however. Following two very dry years (1971, 1972), the native species rebounded immediately (1973 was an unusually wet spring), while the *B. rubens* population required two years to reach its previous density. The native seeds therefore seemed better adapted than the *B. rubens* seeds to weather the severest drought, while the *Bromus* species appeared to reproduce better in the "normal" years. The driest and least productive years of record were 1989 and 1990, but the consequences are as yet unknown.

Some adaptations that give *Bromus* species advantages over desert ephemerals include better seed dispersal adaptations than natives (see Ellner and Shmida 1981, Levin et al. 1984), a greater response to nitrogen by the introduced grasses (Hunter, unpublished data), and a greater proportion of *Bromus* plants inhabiting the fertile soils under shrubs (Soholt and Irwin 1976, R. B. Hunter and K. B. Hunter, unpublished data). One disadvantage that seemed to limit *Bromus* growth in certain years was the fibrous root systems of the grasses as opposed to tap roots of the natives—sparse, frequent rains favored *Bromus*, while deep, infrequent ones favored species with tap roots. Given these genetic differences, one might expect the introduced grasses to find slightly different niches from the natives and possibly add to the diversity of the native flora, rather than diminish it. In the densities occurring in recent years, however, the environment of the desert surface appears

to this author to be radically changed. I suspect that the surface shading by dead *Bromus* stalks, the changed fire frequencies, and the dense population of the introduced *Bromus* species on the "fertile islands" under shrubs will profoundly change the nature and diversity of the native flora.

The mechanisms of the increases in density and biomass of the *Bromus* species are not readily apparent, but they appear to be related to their biological adaptations. They coincided with a series of years wetter than the 1951–1980 average for southern Nevada, which occurred from 1973 through 1988 (NOAA 1989). I have considered, but rejected, the hypothesis that the activities of man were the cause of the rapid increase in *Bromus* densities. Certainly the two species are well adapted to disturbance (Table 1), and man disturbs a great deal of the landscape. Nevertheless, the area disturbed by man on the NTS is not as great as that disturbed by burrowing animals and fires. Furthermore, the range extension for *B. tectorum* appeared to be widespread, and not restricted to the NTS (Young et al. 1987, Robertson 1987, Young and Tipton 1989). Disturbance by man, natural events, and animals is almost ubiquitous. Urban centers, grazing, use of off-road vehicles, and recreational use of public lands promise to maintain disturbance at high levels for the foreseeable future. The Nevada Test Site has been protected from some of those disturbances (grazing, residential development, and recreation) by the security required by the nuclear testing program. The spread of the *Bromus* species should therefore be considered a natural biological phenomenon.

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## SIZE, AGE, AND DENSITY RELATIONSHIPS IN CURLLEAF MAHOGANY (*CERCOCARPUS LEDIFOLIUS*) POPULATIONS IN WESTERN AND CENTRAL NEVADA: COMPETITIVE IMPLICATIONS

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**ABSTRACT.**—Size-density-age relationships in curlleaf mountain mahogany communities were studied in 25 study plots, each  $30 \times 30$  m, in western and central Nevada. The influence of total vegetation cover (site potential) and relative mahogany cover (mahogany dominance) on the observed size-density-age relationships was investigated. A positive linear relationship was found between mean mahogany height and mean mahogany age. A positive nonlinear relationship was found between mean mahogany crown volume and mean mahogany age. Negative nonlinear relationships were found between mean mahogany density and mean mahogany age, and mean mahogany density and mean mahogany crown volume. Strong negative relationships were found between the mean combined density of established seedlings, juvenile, and immature mahogany and mean mahogany age and mean mahogany crown volume. Including total cover in the regression relationships between size, age, and density never increased the  $r^2$  value by more than .05. The addition of relative mahogany cover improved the  $r^2$  value for the relationship between mean mahogany density and mean mahogany crown volume by .28. The strong size-density and age-density relationships found indicate that intraspecific competition is probably occurring in the communities sampled, and that established seedlings, juvenile, and immature plants are the first individuals affected. Direct tests are needed to confirm these relationships.

**Key words:** curlleaf mahogany, size-age-density relationships, intraspecific competition, population dynamics.

An understanding of the relationships between size, density, and age in a plant population is key to understanding the processes of intraspecific competition and population dynamics (Westoby 1977, 1981, Harper 1977). These relationships can be studied based on either the individuals of a species on one site over time or data from a series of different sites of different ages. Because curlleaf mountain mahogany (*Cercocarpus ledifolius* Nutt. T & G) is a slow-growing, long-lived species, the latter method was used.

Relationships between population variables of size, density, and age can be used as indicators of a population's dynamics (Harper 1977). One example is the general relationship between average plant size and the density of a species fully occupying a site. This size-density relationship has been widely represented by the allometric equation  $Y = kP^a$  (White 1981, Long and Smith 1984, Westoby 1984, and Westoby and Howell 1986) where  $Y$  is mean plant size,  $P$  is plants per unit area,

and  $a$  and  $k$  are constants. When plant populations reach full site occupancy, the maximum size-density relationship possible for that site has been obtained and density reductions occur (Hutchings and Budd 1981).

The size-density relationship has been broadly applied to many types of plants but not always consistently (Weller 1987, 1989, Zeide 1987). There have also been questions about the statistical validity of the relationship, in particular the possibility of spurious correlation (Weller 1987). It has been shown in a review of the procedures by Prairie and Bird (1989) that most of the questions regarding statistical validity have resulted from misconceptions about the relationship. They provide criteria supporting these types of analyses.

Models based on size-density relationships have been used to provide a base from which to evaluate the competitive interactions between the individuals in a population (Hutchings and Budd 1981, Long and Smith 1984,

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Gaudet and Keddy 1988). Drew and Flewelling (1979) have demonstrated the practical application of the use of a size-density model in the analysis and management of stand density in Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco) plantations. Size-density models have also been successfully used in stand growth models (Smith and Hann 1984, Lloyd and Harms 1986, Smith 1986).

Most research on plant competition has centered on a phenomenological nonpredictive approach (Gaudet and Keddy 1988). Additional progress requires a predictive approach that allows general principles to be deduced that apply beyond the species and conditions of a particular site or study. Gaudet and Keddy (1988) have shown that plant biomass, plant height, canopy diameter, canopy area, and leaf shape explain most of a plant's competitive ability.

Information on intraspecific competition as related to relationships between size, age, and density in curleaf mahogany communities is nonexistent. The first objective of this study was to quantify size, age, and density relationships in selected curleaf mahogany populations. The second objective was to describe possible reasons for the observed size-age-density relationships. Explanations for the often-noted poor recruitment (Scheldt and Tisdale 1970) of new individuals into mature curleaf mahogany stands were also explored.

#### STUDY SITE DESCRIPTIONS

Curleaf mahogany communities were sampled in 25 study plots on three mountain ranges in western (Peavine Mountain: 9 plots, Carson Range: 4 plots) and central (Shoshone Range: 12 plots) Nevada during May–August 1985.

On Peavine Mountain scattered mahogany occur near 1890 m on west, east, and north aspects but dominate stands only above 1980 m. Mahogany stands on south-facing slopes are found above 2260 m. Individual stands vary in size from 1 to over 300 ha. Smaller stands are most common along rocky ridges and as islands within low sagebrush (*Artemisia arbuscula* Nutt.) communities. Large stands occur on hillsides and are commonly surrounded by mountain big sagebrush (*Artemisia tridentata* var. *caseyana* [Rydb.]

J. Boivin) communities. Annual precipitation averages 36–41 cm and occurs mostly as snow. The average frost-free period is 50–80 days. Curleaf mahogany is largely restricted to the Ticino gravelly fine sandy loam (SCS 1983), with an effective rooting depth of 51–103 cm.

Sampling on the Carson Range occurred in mahogany stands between 1550 and 1890 m. The mixed conifer zone generally occurs above 1900–2000 m. Individual mahogany stands vary in size and tree density as on Peavine Mountain. Average annual precipitation is 36–51 cm and occurs mostly as snow during the winter months. The average frost-free period is 50–80 days. Soils supporting mountain mahogany are Duckhill stony loam, Apmat gravelly sandy loam, and the Fraval-Hirschdale-Jumbo association (SCS 1983). Effective rooting depth varies from 51 to over 154 cm.

Mahogany on the Shoshone Range occur as low as 2150 m on north aspects, but large stands are rarely present below 2380 m. Southern aspects have few mahogany stands below 2600 m. All other aspects have abundant mahogany stands between 2450 and 3050 m. Limber pine (*Pinus flexilis* James) is a common associate above 2900 m. Stand size is variable, ranging from less than 1 to over 300 ha. Smallest stands occur along rocky ridge lines, and largest stands on sloping mountain sides and in bowls below the mountain crest. Annual precipitation averages 41–51 cm; but unlike western Nevada, heaviest precipitation normally occurs early in the growing season (March–June), and summer rainfall is slightly more abundant (Houghton et al. 1975). The frost-free period is 50–80 days. Mountain mahogany tends to be restricted to the Fox mount soil series, specifically Fox-mount gravelly loam (Carol Jett, personal communication). These soils are well drained, moderately permeable, and have an effective rooting depth of 51–103 cm.

Average understory cover in each study area is almost identical (14–15%) (Schultz et al. 1990). Average vegetative cover on the Shoshone Range (98%) is substantially greater than on Peavine Mountain (70%) and the Carson Range (68%) (Schultz et al. 1990). A similar relationship for average curleaf mahogany cover is also present: Shoshone Range 79%, Peavine Mountain 56%, and Carson Range 54% (Schultz et al. 1990).

TABLE 1. Mountain mahogany maturity classes developed from a reconnaissance of mahogany stands near Reno, Nevada.

1. Established seedling	young plants; 2–7 mm basal diameter; smooth bark; plants may be up to 30 cm in height
2. Juvenile	young plants greater than 7 mm basal diameter; smooth bark; plants to 60 cm tall
3. Immature	young plants greater than 1.25 cm basal diameter; smooth bark; plants to 1.5 m tall
4. Young-mature	cracked bark; 1.5–3.0 m tall; crown broadened; may be multistemmed from base; not suppressed
5. Mature	cracked bark; wide full crown; few dead branches; may have several stems from base; may be suppressed; greater than 3 m tall
6. Overmature	cracked bark; may be multistemmed; numerous dead branches; may be greater than 3 m tall; frequently suppressed

## METHODS

### Field Sampling

An initial field reconnaissance near Reno, Nevada, indicated that mahogany stands are composed of individuals categorized into six maturity classes: established seedling, juvenile, immature, young-mature, mature, and overmature (decadent) (Table 1).

Sampling occurred in 30 × 30-m study plots, each having at least one young-mature individual and placed as close to a cardinal aspect as permitted by access and mahogany distribution. Ecotones with adjacent plant communities were avoided. Upper, middle, and lower portions of the mahogany belt were sampled when the elevation range exceeded 500 m.

Mahogany density and maturity class distribution were recorded in each study plot (density/900 m<sup>2</sup>). All mahogany plants, except established seedlings, were measured to obtain crown diameters (the two longest perpendicular diameters) and height. Established seedlings had only crown measurements recorded on plants selected for growth ring analyses.

Crown measurements were used to calculate mahogany cover (%) and mahogany crown volume (m<sup>3</sup>) (Ludwig et al. 1975, Tausch 1980). All measurements were of the green

leaf portion of the canopy and were made to the nearest decimeter (dm).

Four randomly selected individuals from each maturity class present in each study plot were cut to estimate plant age. Relative growth rates (RGR), using growth ring widths (Davis et al. 1972, Brotherson et al. 1980), were also determined on each cross section. If a maturity class had less than four individuals present, all plants were cut for age and growth ring analysis. Cross sections were cut as close to the ground as possible, and from the largest living stem.

Understory vegetation within each study plot was sampled in three randomly located 30-m belt transects (Schultz et al. 1990). Cover was ocularly estimated in 15 shrub quadrats (1 × 2 m) and 30 grass and forb quadrats (20 × 50 cm). Crown cover (%) was estimated for shrub and forb species, and basal area (%) for grasses. The density of current-year mahogany seedlings (density/m<sup>2</sup>) was also recorded in each 1 × 2-m quadrat. Current-year seedlings usually had 4–8 leaves and were less than 2.5 cm tall.

### Data Analysis

Crown diameter, crown height, and crown area (m<sup>2</sup>) were computed for each tree measured. Total crown area and total crown cover (%) values were calculated for each maturity class and study plot by summing the area occupied by individual plants. Average values were determined on each study area.

Relative mahogany cover (mahogany cover divided by total study plot cover) was calculated for each study plot and study area. Crown volume (m<sup>3</sup>) was computed for each mahogany plant using the formula for one-half of an ellipsoid (Tausch 1980). Total and mean values for each maturity class, study plot, and study area were calculated.

Mahogany density (density/900 m<sup>2</sup>) was determined for each study area. Growth ring counts and measurements from the mahogany subsample were made along two sanded radii on each cross section. Growth rings were identified by a single row of relatively large vessels in the springwood (Schultz et al. 1990). Modifications of a technique using acetic acid and zinc oxide (Parker et al. 1976) were used to enhance the contrast between early- and latewood in each annual ring. Time and funding constraints did not allow us to

determine whether false rings were present. Reference chronologies were not available for cross dating.

Yearly growth increments were measured to the nearest 0.01 mm for the 10 years before harvest using a Craighead-Douglas dendrochronograph and a binocular microscope. Age and ring width data from the two radii were averaged to determine a mean value for each cross section. Age data were considered reliable when values from the radii were within 5% of each other. Ring width data were used to calculate the mean stem area increment ([MSAI] [ $\text{cm}^2/10$  years]) of each cross section (Schultz et al. 1990). Mean age, ring width, and MSAI values were summarized for each maturity class in each study area. Estimated mean age values for all maturity classes were based on the subsampled trees. Mean study plot age values were calculated by weighting the mean value of each maturity class by its density, summing, and dividing by total plot density. Study plot means were averaged for mean study area values. Relationships between age and size were not computed for the individual mahogany in each study plot because of the subsampled age data.

Age is an important predictor of a plant's fate only insofar as it affects plant size (Westoby and Howell 1986). Size is considered the primary determinant of survival (Westoby and Howell 1986). Each of the areas we sampled had mahogany stands composed of individuals of various size and age. To focus the analyses on the full range of variation sampled, we pooled data from all three sites.

All analyses of size, age, and density were first done using linear regression techniques. The residuals from these analyses were used to determine which were nonlinear. Nonlinear relationships were then analyzed using an iterative nonlinear regression technique to fit the data to the equation  $Y = aX^b$  (Caceci and Cacheris 1984), where  $Y$  is mountain mahogany density or size,  $X$  is mean mahogany age or mean mahogany crown volume, and  $a$  and  $b$  are constants. This avoided the problems associated with logarithmic transformation of the data for analysis (Payendeh 1981, Brand and Smith 1985).

Following the completion of simple linear and nonlinear regression analyses, multiple linear ( $Y = a + bX + cZ$ ) and nonlinear ( $Y = aX^bZ^c$ ) analyses were performed. Values for

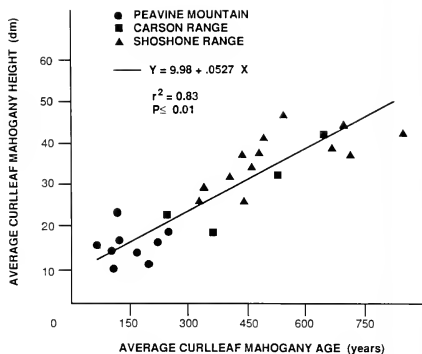


Fig. 1. Major landforms and vegetative communities on the NTS as determined by Beatley (O'Farrell 1976).

total vegetation cover and relative mahogany cover were used for  $Z$  in these analyses. These analyses provide an indication of how site potential (total plant cover) and dominance by mahogany (relative mahogany cover) in the sampled plots affected the size-age-density relationships observed. Methods for independent site potential estimates needed for direct tests of these relationships are not available for mahogany woodlands. Values for total vegetation cover, relative mahogany cover, and nonmahogany cover are from Schultz et al. (1990). The  $r^2$  values for nonlinear analyses were computed according to the methods of Brand and Smith (1985). This  $r^2$  has the same interpretation (% of variation in  $Y$  explained by variation in  $X$ ) as for linear regression. The significance level is  $P < .05$  or greater for all linear regression analyses. Significance levels are not directly available for nonlinear regression. Significance levels for the equivalent analyses using logarithmically transformed data were  $P < .05$  or better.

## RESULTS

### Size-Age-Density Relationships

The relationship between average mahogany height and average mahogany age was the only one found to be linear (Fig. 1). The older the average age of the mahogany in a stand, the greater the average height. Including total cover in a multiple linear regression improved the results,

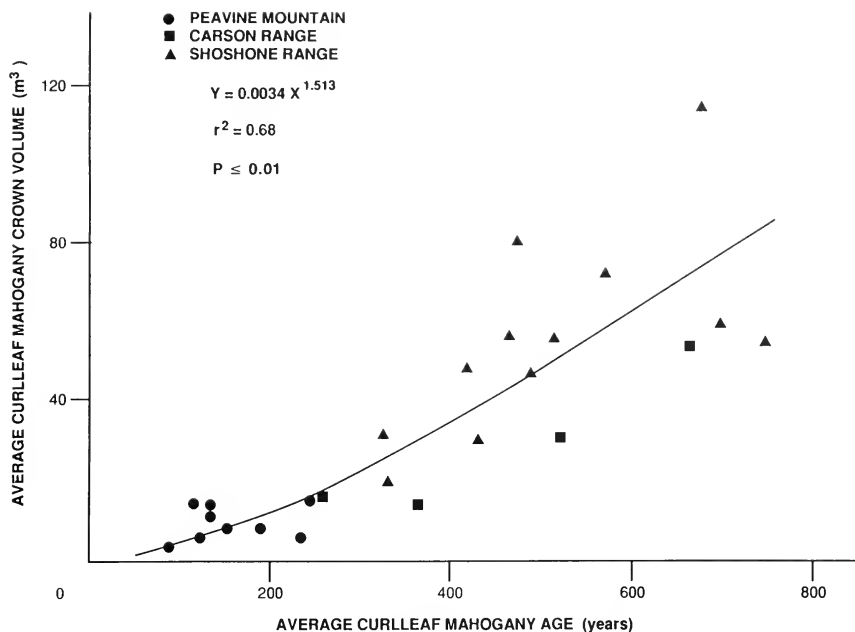


Fig. 2. Nonlinear relationship between average curlleaf mahogany crown volume ( $\text{m}^3$ ) and average curlleaf mahogany age (years) for three sites in Nevada.

$$Y = 2.71 + 0.0449X + 0.121Z, r^2 = .86, P < .001 \quad (1)$$

where  $Y$  is average mahogany height (dm),  $X$  is average mahogany age (years), and  $Z$  is the total vegetal cover (%) of the plots. The contribution of  $Z$  was significant ( $P < .05$ ). Sites with higher total plant cover (%) tended to have taller mahogany for a given age than sites with lower total vegetal cover. This seems consistent with total cover representing site potential.

Average mahogany crown volume increased with average mahogany age (Fig. 2). Including total plant cover or relative mahogany cover for  $Z$  in a multiple nonlinear regression analysis increased the  $r^2$  by less than .01 over that in Figure 2. The increase in mahogany crown volume with increasing stand age did not appear to be affected by either total plant cover or level of mahogany dominance in the sampled plots.

Average mahogany density had a strong nonlinear relationship with average mahog-

any age (Fig. 3). Including total plant cover or relative mahogany cover for  $Z$  in a multiple nonlinear regression analysis increased the  $r^2$  by less than .01 over that in Figure 3. The decrease in mahogany density with increasing stand age for the sampled stands was independent of both total plant cover and mahogany dominance.

Mahogany density was highest in study plots that had an average age of less than 150 years, but it was substantially lower in study plots that had an average age of 250–300 years. Study plots with a mean age beyond 300 years had similar densities.

The density of established seedling, juvenile, and immature maturity classes had a similar, but steeper, negative relationship to average mahogany age as in Figure 3,

$$Y = 103428X^{-1.486}, r^2 = .81 \quad (2)$$

where  $Y$  is the density of established seedling, juvenile, and immature mahogany (density/900 $\text{m}^2$ ), and  $X$  is average mahogany age

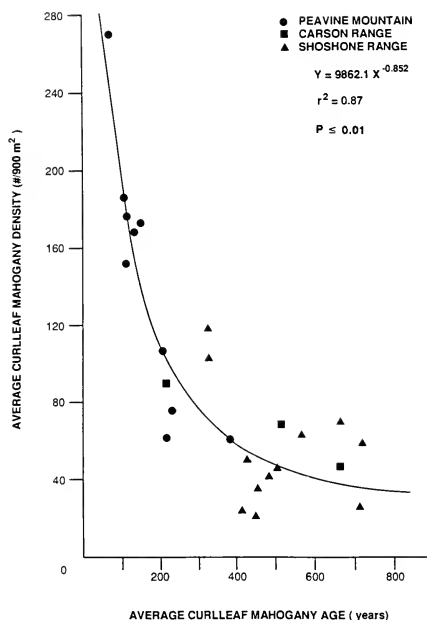


Fig. 3. Nonlinear relationship between average curlleaf mahogany density (#/900 m<sup>2</sup>) and average curlleaf mahogany age (years) for three sites in Nevada.

(years). The addition of total plant cover (*Z*) to the relationship in Equation 2 had the greatest improvement on *r*<sup>2</sup>, but the improvement was less than .02.

Mahogany density had an inverse nonlinear relationship with average mahogany crown volume (Fig. 4). Including relative mahogany cover for *Z* in a multiple nonlinear analysis improved the relationship,

$$Y = 0.0213X^{-1.48}Z^{3.051}, r^2 = .88 \quad (3)$$

where *Y* is mahogany density (density/900m<sup>2</sup>), *X* is average curlleaf mahogany crown volume (m<sup>3</sup>), and *Z* is relative mahogany cover (%). For the same density, sites with higher mahogany dominance (relative mahogany cover) had larger plants than sites with lower mahogany dominance. The indication is that there may be a relationship between site potential and the ability of a given density of mahogany to dominate a site. The better the site, the larger the individual plants can be-

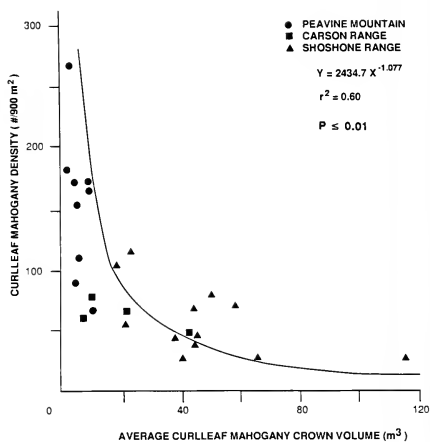


Fig. 4. Nonlinear relationship between average curlleaf mahogany crown volume (m<sup>3</sup>) and curlleaf mahogany density (#/900 m<sup>2</sup>) for three sites in Nevada.

come. An independent measure of site potential would be necessary to directly test this.

The density of reproduction, juvenile, and immature maturity classes had a similar, but steeper, negative nonlinear relationship with average crown volume as in Figure 4,

$$Y = 505X^{-1.15}, r^2 = .78 \quad (4)$$

where *Y* is the density of reproduction, juvenile, and immature mahogany (#/900m<sup>2</sup>), and *X* is average mahogany crown volume (m<sup>3</sup>). The addition of either mahogany or nonmahogany cover did not improve the relationship. The negative effect of large mahogany on mahogany seedlings appears generally independent of the relative levels of mahogany and nonmahogany cover. However, the addition of total plant cover (%) for *Z* improved the relationship:

$$Y = 0.510X^{-1.27}Z^{1.69}, r^2 = .83. \quad (5)$$

For stands with the same mean mahogany crown volume, the density of young mahogany tended to be slightly higher on plots with higher total cover. This may be a reflection of better site conditions somewhat offsetting the suppression of the younger mahogany by the dominant individuals. This possibility needs additional study.



## DISCUSSION

Strong size, age, and density relationships were present in the mountain mahogany communities sampled (Figs. 1–4). Stands on Peavine Mountain, the Carson Range, and the Shoshone Range appeared to follow the same general trend. Relatively early in stand development (mean mahogany age less than 250–300 years) increases in mahogany size are accompanied by sharp declines in stand density. The change in the slope of the regression line that occurred beyond an average mahogany age of 250–300 years coincides with mahogany communities dominated by large, mature individuals (Schultz et al. 1990). These sites were mostly in the Shoshone Range. After mean mahogany age exceeded 300 years, mahogany density continued to decline with increasing stand age, but the rate of decline was reduced.

As mahogany stands increase in average age, average canopy volume and height of the individuals present increase (Figs. 1, 2, Schultz et al. 1990). As average canopy height and volume increase, stand density declines (Fig. 4, Eq. 3). This increase in plant size, together with a concomitant decrease in plant density with age, reflects the size-density relationships reported for many plant populations (Harper 1977).

Eventually, increases in individual plant size cause interference between individual plants and competition for essential resources (Hutchings and Budd 1981). As growth continues, a point is eventually reached where the habitat can support no additional biomass. Further growth can occur only when mortality occurs among existing plants. The strong size-density and age-density relationships present in Figure 4 and Equation 2, respectively, indicate that competition is probably occurring in the mountain mahogany communities sampled. Total stand density declines sharply as mean plant size increases. The density of the youngest individuals also declines, but more rapidly, as average mahogany age increases.

Gaudet and Keddy (1988) have shown that plant biomass explains a substantial part of a plant's competitive ability. Plant height, canopy diameter, canopy area, and leaf shape explain most of the residual variation. Biomass was not measured in this study, but vol-

ume measurements can be substituted for biomass, since studies have shown that volume and biomass are isometrically related (White 1981). Figure 4 indicates that average curlleaf mahogany crown volume, hence biomass, has a strong negative relationship with stand density. Average stand age, in itself, has no influence on a stand's population dynamics. As stands age, however, physical dimensions, such as average crown volume, average biomass, and average crown diameter, increase; and these physical attributes undoubtedly influence competitive interactions.

The inverse relationship of mahogany density and average mahogany crown volume (Fig. 4) was improved substantially by including relative mahogany cover (mahogany dominance) in the analysis (Eq. 3). This situation is similar to data reported by Gaudet and Keddy (1988). In their work plant height, canopy diameter, and canopy area further explained a plant's competitive ability beyond biomass alone.

A reduction of growth rates in individual plants relative to their potential can be an indication of plant competition (Long and Smith 1984). Relative growth rates, as represented by average ring width (mm), and mean stem area increment [(MSAI) ( $\text{cm}^2/10 \text{ yr}$ )] for each study plot for the last 10 years are reported in Schultz et al. (1990). Mountain mahogany stands on Peavine Mountain had the greatest RGR, as represented by average ring width and MSAI. If ring width and MSAI values on Peavine Mountain are assumed to be the maximum potential growth rates obtainable by curlleaf mahogany, then the RGRs in the Carson and Shoshone ranges are substantially reduced relative to the species' potential. This occurred despite similar soils and climate.

Previous work (Schultz et al. 1990) found that mean mahogany size and total mahogany crown volume are significantly ( $P \leq .05$ ) less on Peavine Mountain than on the Carson and Shoshone ranges. Because larger individuals have a competitive influence considerably beyond what is proportional to their size (Bella 1971), it is likely that intraspecific competition is greatest in Carson and Shoshone ranges.

Since mahogany size is a function of stand age (Figs. 1, 2), we interpret the greater steepness of the regression lines in Equations 2 and 5 compared with Figure 3 to imply that

established seedling, juvenile, and immature mahogany are the first individuals in a stand affected by increasing mahogany size and, therefore, intraspecific competition. If intraspecific competition affected individuals of all sizes equally, the slope of the regression lines for all three analyses would be similar. Other research (Bella 1971, Weiner 1984, Grace 1985) has shown that the youngest and smallest individuals present in a population are the plants most affected by intraspecific competition. Schultz et al. (1990) found that Peavine Mountain has a population structure in which 62% of the plants present were from the established seedling, juvenile, and immature maturity classes. In contrast, the Carson and Shoshone ranges, respectively, had 9 and 18% of their population structure composed of individuals from these maturity classes. Mean mahogany crown volume on Peavine Mountain was 3.4 and 6.8 times smaller than on the Carson and Shoshone ranges, respectively.

As mean mahogany size continues to increase, few, if any, established seedling, juvenile, and immature mahogany are left. This situation is similar to other studies that have noted poor or absent reproduction as an indicator of competition (Long and Turner 1975, Oliver 1981).

The often-noted poor recruitment of new mahogany into mature stands can probably be explained, to some degree, by the size-density relationships observed. Data on estimated population growth rates (Schultz et al. 1990) show that mahogany communities with large average crown volumes (Shoshone and Carson ranges) have had slow population growth rates since the oldest individuals were established 500 or more years ago. Where average crown volume is relatively small (Peavine Mountain), established seedling, juvenile, and immature mahogany are abundant, and the population size has increased steadily since the oldest individuals became established.

Mahogany communities with small average crown volumes have comparatively lower mahogany cover (Schultz et al. 1990). Low mahogany cover increases the incidence of canopy gaps, which appear to be essential for the recruitment of young mahogany into the population (Schultz et al. 1990). Canopy closure has been found to indicate competition is occurring (Assman 1970). Mahogany

cover in the Shoshone Range averaged 79%, but it approached or exceeded 100% in almost half the study plots sampled. In study plots with less than 100% mahogany cover the spatial structure of the community is such that mahogany thickets with cover greater than 100% are common (personal observation). The Carson Range has a similar structural appearance.

Low densities of established seedling, juvenile, and immature mahogany can also be due to a lack of viable seed, poor seedling establishment, or poor recruitment of established seedlings into successively older maturity classes. Lack of viable seed did not appear to be a problem, since the Shoshone Range had a current-year seedling density of  $2.0/\text{m}^2$ . Personal observation indicates that stands with high mahogany cover and large average crown volumes have deep and persistent litter cover. Deep plant litter probably limits mahogany seedling survival and establishment (Schultz et al. 1990). Seedlings rooted in deep litter frequently do not have their roots established in mineral soil, and as soon as the litter material dries out the seedlings become desiccated and die (personal observation). Marquis et al. (1964) and Keever (1973) have observed that the establishment of relatively small-seeded species is adversely affected by continuous litter cover.

## CONCLUSIONS

Curlleaf mountain mahogany stands composed of large, mature individuals have lower total stand densities and lower densities of established seedling, juvenile, and immature mahogany. Over time intraspecific competition apparently occurs and probably intensifies as a result of increasing plant size. Intraspecific competition reduces the growth rates of all maturity classes below the potential growth rates for the species. Competition also appears to increase mortality in the smallest individuals present. This explains the often-noted poor recruitment (Scheldt and Tisdale 1970) of new individuals into mature mahogany stands. Increased mortality in the smallest and youngest individuals results in a maturity class structure dominated by relatively few, but very large, mature individuals. The plentiful establishment of young mahogany is probably not possible unless stands composed

of large, mature trees have their canopies opened up, and intraspecific competition is reduced.

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## FIELD ACETYLENE REDUCTION RATES OF *LUPINUS ARGENTEUS* ALONG AN ELEVATIONAL GRADIENT<sup>1</sup>

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**ABSTRACT.**—The effects of elevation and environmental parameters associated with elevation on the dinitrogen fixation rates,  $N_2[C_2H_2]$ , of a North American lupine species were evaluated. *Lupinus argenteus* Pursh plants growing at five elevations on Francis Peak, Utah, were sampled weekly throughout the growing season. The highest elevation site had the greatest frequency of nodulated plants. Influence of the environmental and physiological variables on fixation activity varied with elevation and the mean time of sampling. Soil moisture, nodule dry weight, and air temperature were important. Less than one-half of the observed variation in fixation rates,  $N_2[C_2H_2]$ , was accounted for by variation in the associated independent variables. Nevertheless this study documented that nodulated plants of *L. argenteus* were capable of actively fixing nitrogen at a range of elevations on Francis Peak.

**Key words:** ecology, ecophysiology, legume, nitrogen fixation, nodulation, rangeland, *Rhizobium lupini*.

Species of *Lupinus* are found from timberline to seacoast in much of the western United States (Phillips 1955). Their importance in the nitrogen economy of range ecosystems has not been extensively investigated. Native legumes are believed to supply biologically fixed nitrogen to the semiarid rangeland plant communities in which they occur, but their role has not been well documented (Farnsworth et al. 1978). Johnson and Rumbaugh (1981) studied the acetylene reduction rates,  $N_2[C_2H_2]$ , of nodules of 34 legume species growing on mountain grassland sites, big sagebrush-dominated sites, and cultivated former big sagebrush sites in northern Utah. Nodules were present and active in some species even during the driest part of the growing season. However, 13 of the 17 species of lupines native to North America that were growing in a cultivated nursery environment were not nodulated even though the seeds had been inoculated with a commercial peat-base inoculum.

Pegtel (1980) investigated *Lupinus laxiflorus* Dougl., *L. lepidus* Lindl., and *L. polyphyllus* Lindl. on undisturbed sites with serpentine and nonserpentine soils on Mt. Stuart in the Wenatchee Mountains of Washington. All root systems had nodules, and serpentine and nonserpentine populations had the same

number of nodules per plant. Additional laboratory research showed that the wild strains of *Rhizobium lupini* all fixed atmospheric nitrogen but that their effectiveness was variable and generally lower than commercially available strains. *L. polyphyllus* had a higher effectivity of nodulation than *L. argenteus* and *L. leucophyllus* in a greenhouse study (Walsh et al. 1983).

McNabb and Geist (1979) measured nitrogen fixation rates ranging from 1 to 10 kg N/ha for four perennial *Lupinus* species native to the Pacific Northwest. There was a significant seasonal variation in nodule biomass of two of the species. The potential for lupine nitrogen fixation was believed to be dependent primarily on nodule biomass. Similarly, whole plant estimates of nitrogen fixation by high-altitude legumes in Montana and Utah were 5 to 15 times greater for *L. argenteus* than for native *Astragalus* and *Trifolium* species (Johnson and Rumbaugh 1986). The difference was ascribed to the greater nodule mass of the lupine.

The objective of this study was to assess the effects of changes in elevation and environmental parameters associated with elevation on nitrogen fixation rates of a native lupine species growing on a semiarid mountain rangeland in the intermountain region of the western United States.

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## SITE DESCRIPTIONS AND METHODS

The five study sites were located on west or northwest aspects of Francis Peak in the Wasatch Range of north central Utah. All were within or adjacent to the Davis County Experimental Watershed, which was established in 1930 as a United States Forest Service-administered research area. The climate and vegetation of the watershed is generally representative of a large part of the low- to mid-elevation (1500 to 2800 m) mountain country in the intermountain area. Summers are short, cool, and dry. Most summer storms are convective thundershowers of less than six hours duration (Farmer and Fletcher 1971). The highest average annual precipitation of 1043 mm occurs on the upper part of the watershed. Soil moisture depletion begins immediately after snowmelt and continues to increase at a rapid rate into July (Johnston and Doty 1972). Lupines are most common on Cryoboroll soils with slopes of 8 to 30%. Associated species include *Agropyron cristatum* (L.) Gaertn., *Artemisia tridentata* Nutt., *Bromus carinatus* H. & A., *Carex* sp., *Chrysothamnus nauseosus* (Pall.) Britt., *Madia glomerata* Hook., and *Symphoricarpos* sp.

Study sites with adequate numbers of *L. argenteus* plants for sampling throughout the growing season were selected at five elevations. These populations were located at mean elevations of 1478, 2027, 2256, 2454, and 2713 m. Vegetation along the elevational gradient varied from a desert shrub association near the base of the mountain to a sub-alpine meadow at the highest site. One to five representative plants were chosen at approximately weekly intervals at each elevation throughout the growing season. Sampling began on 4 June 1980 at the lowest elevation and was terminated on 21 October 1980 at the highest elevation.

Leaf water potential was measured on each plant by standard pressure chamber techniques (Scholander et al. 1965), the shoot was cut at the soil level for dry biomass weight, and the root system was excavated. Excised root segments with attached nodules were used for the acetylene reduction procedures. The techniques described by Waughman (1971) and used by Westermann and Kolar (1978) and Johnson and Rumbaugh (1981) were followed with the exception of limiting

the incubation period to one hour. The hour of sampling was recorded as well as the numerical day of the calendar year. Sampling was limited to the hours between 10:00 a.m. and 4:00 p.m. each day. Care was exercised to shield exposed nodules and incubation chambers from direct sunlight. Air temperature was measured with a mercury thermometer and soil temperature with a bimetallic dial thermometer with a 10-cm probe. Soil samples for moisture determinations were collected from 0–20 cm and 20–40 cm depths.

## RESULTS AND DISCUSSION

Air and soil temperatures tended to be lower at the higher sites along the gradient (Table 1). Soil moisture throughout the depth of the profile tested was higher at the 2713-m site than at the four lower elevations. The 1478-m area was situated on a west-facing slope, and soils at this site were deeper than at the other locations. The lupine plants had large, woody tap roots, and nodules were located only on lateral roots. The study area at 2027 m sloped sharply toward the south and was shaded a considerable part of the day by the mountain peak. This location also was the only one of the five sites with trees that shaded the lupine plants. These shading factors probably resulted in the soil temperatures being lower than for sites immediately higher and lower on the mountain side. The 2256-m elevation appeared to be the most xeric of all the study areas. Lupines were growing intermixed with a dense population of *Artemisia tridentata*. The soils at the 2454- and 2713-m elevation sites were shallow and rocky. *L. argenteus* grew in almost pure stands with only a few plants of other forbs as associated species. Plants at the highest site were more uniform in size than at lower elevations, they had less-extensive root systems, and it was easier to find nodules than at the other four study areas.

Plants at the extreme elevations were smaller than those at intermediate elevations (Table 1). Shoot weight was more closely associated with soil moisture than with mean temperatures. The simple correlation of above-ground plant weight with soil moisture in the 20–40 cm zone was  $r = -.27$  ( $P < .01$ ). All other coefficients were of lower magnitude. Shoot weight was positively associated

TABLE 1. Environmental and physiological variables measured at five sites on Francis Peak, Utah, during 1980. Acetylene reduction activity,  $N_2[C_2H_2]$ , of nodulated *Lupinus argenteus* plants is expressed as  $\mu$  moles of ethylene/h/g nodule fresh weight.

Variable	Site elevation (m)					Variable mean	L. S. D. (0.05)
	1478	2027	2256	2454	2713		
Number of plants (N)	67	62	21	81	76	—	—
Frequency of nodulated plants (%)	45	44	24	32	97	53	—
Air temperature (C)	22.4	22.5	20.9	18.8	13.6	17.8	3.0
Soil temperature (C)	17.7	13.8	15.1	17.5	10.7	13.8	2.3
Soil moisture 0–20 cm (g/kg)	70	63	47	76	105	87	24
Soil moisture 20–40 cm (g/kg)	74	70	93	84	125	101	26
Leaf water potential (–MPa)							
Nodulated plants	8.3	10.4	11.2	12.2	9.1	9.7	1.8
Nonnodulated plants	8.2	9.8	16.8	13.1	8.7	11.4	2.0
Shoot weight (g)							
Nodulated plants	17.0	25.7	4.5	9.8	9.5	13.5	12.5
Nonnodulated plants	15.0	50.7	41.8	16.8	12.9	27.2	20.4
Root weight (g)							
Nodulated plants	57.2	45.4	4.7	14.3	6.5	23.6	41.6
Nonnodulated plants	22.3	64.2	65.4	26.4	12.6	38.6	28.5
Nodule weight (g/plant)	0.04	1.21	0.10	0.10	0.43	0.42	N.S.
Day of year	157	167	170	213	230	202	18.7
Hour	11.1	13.3	11.2	13.6	11.4	12.0	0.6
$N_2[C_2H_2]$ activity ( $\mu$ moles/h)	8.4	4.4	6.6	2.7	11.4	8.2	4.3

Difference between means required for statistical significance ( $P < .05$ ).

NS = not significant.

with air and soil temperatures, leaf water potential, day of year, and root weight, but negatively related to the other variables.

Plants for which nodules could not be found weighed more than those with nodules. Average shoot weight of the 145 plants without nodules was 27.2 g in contrast to 13.5 g for the 162 nodulated plants. This was probably a function of plant age. Young, actively growing plants of *L. argenteus* were better nodulated than more mature plants. Nodulated plants averaged 45, 44, 24, 32, and 97% at the five sites along the gradient, with the highest elevation having the greatest proportion of plants with nodules. Differences in shoot weight of nonnodulated and nodulated plants at the highest and lowest elevations were not statistically significant ( $P > .05$ ), whereas differences between the means for the three intermediate elevation sites were significant ( $P < .05$ ). Nodules of *L. argenteus* are perennial, and nodule number was assumed to be relatively stable throughout the duration of the study.

Differences in root biomass also were noted, but these could have been caused by incomplete excavation of the root systems of

plants for which nodules were easily found. Pegtel (1980) observed that all root systems of *L. laxiflorus*, *L. lepidus*, and *L. polyphyllus* had functioning nodules. Although roots were excavated to as deep as 100 cm in the present study and the roots carefully examined, nodules might have been overlooked or the excavation might not have been deep or extensive enough to expose all nodules. Rocky soil impeded the digging of some plants, especially at the 2454-m study area. Holter (1978) was of the opinion that determination of root biomass and number of nodules was impractical in the field. He believed that acetylene reduction rates related to these quantities would not be useful and that rates should be expressed on a per plant, per shoot, or per gram of aboveground biomass basis.

Dinitrogen fixation rates of other native perennial lupine species were lower for older plants and plants growing on droughty sites than for younger plants and plants growing on more favorable sites (McNabb and Geist 1979). Acetylene reduction activity for *L. argenteus* on Francis Peak was much greater for plants at the 2713-m elevation than at the four lower sites. The rate of 11.4  $\mu$  moles of

TABLE 2. Simple correlations ( $r$ ) of environmental and physiological variables with acetylene reduction rates,  $N_2[C_2H_2]$ , of nodulated *Lupinus argenteus* plants. Rates are expressed as  $\mu$  moles of ethylene/h/g nodule fresh weight.

Correlated variable	Study sites		
	All	Early group	Late group
Elevation (m)	0.06	0.15	-0.15
Air temperature (C)	-0.04	-0.08	0.49**
Soil temperature (C)	-0.10	-0.15	0.36**
Soil moisture 0-20 cm (g/kg)	0.16*	0.21*	-0.31*
Soil moisture 20-40 cm (g/kg)	0.20*	0.20*	-0.28*
Leaf water potential (-MPa)	-0.18*	-0.14	0.08
Shoot weight (g)	0.05	0.03	0.30*
Root weight (g)	-0.03	-0.01	-0.04
Nodule weight (g)	0.10	-0.04	0.38**
Day	0.00	-0.18	-0.13
Hour	-0.28**	-0.01	-0.04

\* $P < .05$ .\*\* $P < .01$ .TABLE 3. Rank of importance of independent variables, standardized multiple regression coefficients (Beta), and multiple correlation coefficients ( $R$ ) from the stepwise multiple regression analysis of acetylene reduction rates,  $N_2[C_2H_2]$ , of nodulated *Lupinus argenteus* plants. Rates are expressed as  $\mu$  moles of ethylene/h/g nodule fresh weight.

Independent variable	Study area grouping					
	All		Early		Late	
	Rank	Beta	Rank	Beta	Rank	Beta
Elevation (m)	6	0.12	5	0.30	7	-0.22
Air temperature (C)	7	0.15	9	0.13	1	0.28
Soil temperature (C)	11	0.01	3	-0.25	6	0.55
Soil moisture 0-20 cm (g/kg)	8	-0.08	1	0.15	10	-0.09
Soil moisture 20-40 cm (g/kg)	2	0.23	10	-0.08	8	0.29
Leaf water potential (-MPa)	5	-0.17	11	-0.02	5	-0.30
Shoot weight (g)	4	0.09	7	0.10	3	0.27
Root weight (g)	10	0.01	8	0.05	4	-0.36
Nodule weight (g)	3	0.13	4	-0.10	2	0.41
Day	9	0.06	6	-0.20	11	-0.01
Hour	1	-0.22	2	-0.18	9	-0.10
$R$		.38		.36		.74

ethylene per hour per g of fresh nodule weight at the 2713-m elevation was 52% greater than the average rate of the 88 plants from the lower elevations.

Simple correlations (Table 2) indicated that soil moisture, leaf water potential, and hour of sampling were significantly ( $P < .05$ ) associated with reduction activity. An examination of the means in Table 1 led to grouping of the study areas into two categories according to mean time of sampling. Nodules from the 2027- and 2454-m elevations were collected later in the afternoon than those from the 1478-, 2256-, and 2713-m areas. The early group mean sampling time and standard error were  $11.3 \pm 0.01$  hours, but those of the late group were  $13.4 \pm 0.01$  hours, or more than 2 hours later in the day. Soil moisture was the only factor correlated with activity of nod-

ules from plants in the early group. Air and soil temperatures, shoot and root weights, as well as soil moisture, were correlated with activity of nodules from plants in the late group. *Trifolium pratense* L. and *Medicago lupulina* L. fixed very little nitrogen when soil moisture was reduced to 8% or less (Holter 1978). Table 1 shows that soil moisture averaged less than that in the surface to 40 cm depths at the four lower study areas on Francis Peak.

Causal relationships among the variables were examined by forward stepwise multiple regression. When all available data were considered, hour of day at which the plants were sampled and soil moisture below 20 cm were the two most influential independent variables determining acetylene reduction rates (Table 3). They jointly generated a multiple

correlation coefficient,  $R$ , of .27 and explained 7% of the variation in per plant nitrogen fixation activity,  $N_2[C_2H_2]$ . Peak activity occurred from 11:00 a.m. to 12:00 noon when the rate averaged 12.0  $\mu$  moles of ethylene per hour per g nodule fresh weight. Samples taken the preceding hour produced a reduction rate of only 7.2  $\mu$  moles. Mean rates then dropped to 8.4, 5.0, 3.1, 2.6, and 3.5  $\mu$  moles for subsequent one-hour intervals in the afternoon.

Hour of sampling and leaf water potential were positively and significantly ( $P < .05$ ) associated,  $r = .47$ . The impact of hour on acetylene reduction activity probably was due to increased drought stress as the day progressed. This seemed to be particularly true at the 2713-m elevation, which was sampled at four times. One plant sampled at 10:00 a.m. had a leaf water potential of  $-0.96$  MPa, whereas 47 plants sampled at 11:00 a.m. averaged  $-0.78$  MPa. Drought stress then increased markedly, as the 19 plants sampled at 12:00 p.m. had an average leaf water potential of  $-1.13$  MPa. The stress increased still further for the 7 plants sampled at 1:00 p.m., which averaged  $-1.24$  MPa.

Air temperature changed from a low of 15.4 C at 11:00 a.m. to a high of 26.7 C at 4:00 p.m. Air temperature was positively correlated with acetylene reduction activity and was the single most important independent variable when data from the late grouping of study areas were considered (Table 2). Nodule weight was the second most influential variable for the late group and also was important for the early group (Table 3). This was true even though the activity was expressed on a gram nodule fresh weight basis. The degree of hydration of nodules apparently played a role in the nitrogen fixation rates of these plants.

The other independent variables were of lesser value in predicting nitrogen fixation activity. Shoot and root biomass were strongly related to acetylene reduction in four legume species studied by Holter (1978). These were of lesser importance in this study of *L. argenteus*. However, variation in the 11 independent parameters measured and listed in Table 3 explained only 14% of the observed variation in activity. The remaining 86% of the variation in fixation was caused by factors not accounted for in this study, but which must have been, in some way, related to the time of sampling. Separation of the study areas into

two groups on the basis of mean sampling time resulted in much stronger predictive relationships for the late group. The multiple correlation coefficient was  $R = .74$  (Table 3), and the predictive function explained more than half the observed variation in acetylene reduction rates. For plants in the early group, factors other than those measured in this study profoundly influenced the dinitrogen fixation rates of *L. argenteus* plants on the slopes of Francis Peak. Although acetylene reduction rates of *L. argenteus* could not be accurately predicted from the variables evaluated in this study, plants of *L. argenteus* were nodulated and capable of reducing acetylene along an elevational gradient on Francis Peak.

#### ACKNOWLEDGMENTS

This work was supported by U.S. Department of Agriculture Grant 5901-0410-9-0277-0 and the U.S. Department of Agriculture, Agricultural Research Service, and the Department of Range Science, Utah State University, Logan, Utah, under Cooperative Agreement No. 58-9AHZ-0-477. We gratefully acknowledge the capable technical assistance of Dennis Rinehart and Michael Huffman.

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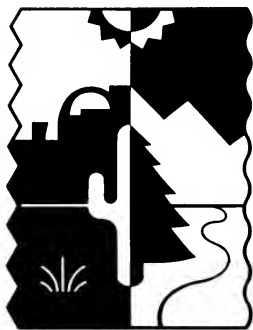
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GUIDELINES  
FOR MANUSCRIPTS  
SUBMITTED TO

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T H E  
**G R E A T B A S I N**  
**N A T U R A L I S T**

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JUNE 1991

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## GUIDELINES FOR MANUSCRIPTS SUBMITTED TO THE GREAT BASIN NATURALIST

June 1991

The following information is presented to provide authors with guidelines and examples to use in preparing manuscripts submitted to the *Great Basin Naturalist*. Although this is not a comprehensive treatise, we believe the guidelines address some of the most common problems encountered by our authors. We recommend the *CBE Style Manual*, 5th edition (Council of Biology Editors, Suite 1200, 230 N. Michigan Avenue, Chicago, IL 60601-5961 USA; \$24), for more in-depth discussions.

### Manuscript Preparation

Type manuscripts on standard bond (22 × 28 cm), leaving 2.5-cm margins on all sides, and submit three copies to the *Great Basin Naturalist*. Please do not send diskettes. Manuscripts printed on a dot-matrix printer should be near-letter or letter quality. To allow reviewers and editors sufficient space for notations, we require double-spacing throughout the manuscript—title page, abstract, text, literature cited, appendices, tables, and figure legends. Either 12-pitch (elite) or 10-pitch (pica) type is acceptable (10-pitch is preferred); right-margin justification is also acceptable. However, if right justification is used, avoid hyphenating words at the ends of lines. This includes both hyphenated words and words divided between syllables. (Hyphenation should be turned off on word-processing equipment.) Number all pages consecutively but omit the number on the title page.

Manuscripts may be submitted as either scientific papers or notes, the major difference being the lack of an abstract in notes (see section under Abstract). In addition, notes are generally shorter communications.

**Title page.** Included on the title page are the title, names and addresses of authors, a running head, and footnotes to indicate change of address. Also, indicate the author to

whom correspondence should be addressed if other than the first author.

- The *title* should be specific and concise (no longer than 15 words). It identifies the article's content or main topic rather than its conclusions. If appropriate, it should include the name of the organism(s) involved. The use of order and family names for species that may be unfamiliar to many readers is appropriate.
- To avoid confusion, we recommend using *full names of authors* rather than initials. Omit academic degrees and professional positions, but cite the department and institution in which the research was done, also the *mailing address* and postal code. If the present address differs from the research institution, include the updated address for correspondence and reprint requests.
- Please provide a *running head* of fewer than 40 letters and spaces. This is a shorter, but nevertheless descriptive, version of the title; it will appear at the top of each right-hand page of the published article.

**Abstract.** The abstract aids the reader in comprehending the essence of the author's research. It should state the objectives and purpose of the study, methods and/or materials used, results, and conclusions of the research. If appropriate, scientific and common names of organisms should be included, with special emphasis on new taxa or distribution

records. Limit the abstract to approximately 250 words.

- Following the abstract are 6–12 *key words*, listed in order of decreasing importance, to be used for indexing. These words should reflect the central topics of the article and may be from the title, abstract, or text. Please list key words for both notes and articles.

**Text.** The significance of the text, or, more specifically, the author's prose style, cannot be underestimated. Ultimately, a scientific article must capture the attention of its readers by the importance of its content and its clarity of expression. Chapter 5, *Prose Style for Scientific Writing*, in the *CBE Style Manual* offers helpful suggestions for achieving succinctness and clarity, and avoiding verbiage and distressing grammatical errors.

Although frequently avoided, particularly in scientific articles, the active voice is the one in which people usually speak and write. It is perfectly acceptable and very useful in scientific writing. Not only is active voice ("We determined") less wordy and ambiguous than passive voice ("It was determined"), but its use is also less likely to result in dangling participles and other misplaced modifiers. When appropriate, use active voice.

Verb tense is another area that deserves comment. Completed procedures and observations are described in the past tense ("was," "were"), but present tense is used when presenting directions, conclusions, generalizations, and references to stable or current conditions.

Because *Great Basin Naturalist* articles cover diverse disciplines, we ask our authors to avoid excessive use of unfamiliar abbreviations, jargon, and overly technical vocabulary. Such terms hinder understanding by members of other disciplines and prevent a free exchange of ideas.

For maximum clarity, the body of the text should be divided into the following sections.

- **Introduction.** The introduction need not be long, but it must adequately introduce the research. At the end of the introduction, clearly state the purpose of the research.
- **Methods.** The methods section should contain all the information necessary for other researchers to duplicate the study. The description of the experimental or sampling design

should be clear to the reader. Use a simple figure to present this information if it helps the reader understand the procedures. Another vital part of this section is a description of all statistical procedures used.

- **Study Site Description.** It may be appropriate to include a description of the study area in a separate section. This usually precedes the methods section, but it may also be contained within that section.

- **Results.** The results should be separate from the discussion. In this section, state the results using text, figures, tables, or any workable combination thereof. This section is not for the interpretation of results.

- **Discussion.** The discussion is the forum in which the study results are interpreted and compared with results from other studies. Interpretations should be consistent with results, and they should correspond with the stated purpose(s) of the research.

We highly recommend the following article as one that is helpful to authors in writing and critiquing their own work:

Kuyper, B. J. 1991. Bringing up scientists in the art of critiquing research. *BioScience* 41:248–150.

Easily understood, effectively placed headings and subheadings help the reader quickly grasp the content and structure of the paper. The *Great Basin Naturalist* uses three levels of headings within textual material.

- **Primary headings** are centered in all capital letters with space above and below. In general, primary headings should be restricted to STUDY AREA, MATERIALS AND METHODS, RESULTS, DISCUSSION, CONCLUSIONS, ACKNOWLEDGMENTS, LITERATURE CITED, and APPENDIX, or variations of the above. Do not use INTRODUCTION as a heading.

- **Secondary headings** are centered in upper- and lowercase letters with space above and below.

- **Tertiary headings**, set in all capitals, are indented from the left margin and followed by a period and a 1-em dash (two hyphens in typescript). Do not use secondary or tertiary headings unless major sections are long and/or the text is complex. In articles requiring only two levels of organization, tertiary headings should be used directly under primary headings.

**Literature Cited.** References to published literature and unpublished documents used

in an article are cited in both the text and a separate bibliographic section.

References in the text are cited by author and date: e.g., Potter (1980) or (Potter 1980). Multiple citations should be separated by commas and listed in chronological order (Baker 1968, Flake 1973, Agnew 1986). In citations having more than two authors, use "et al." after the name of the first author (MacCracken et al. 1985).

Use the heading LITERATURE CITED for the list of references following the text. Include only references actually cited in the text. No reference should be included unless the pertinent publication facts have been verified against the original document. Page numbers seem to be particularly susceptible to transposition and other typographical errors. The responsibility for accuracy of reference material lies with the author, not the copy editor.

The list of literature cited must be alphabetical by authors' surnames. Initials are usually sufficient for given names unless confusion would result when family names and initials are identical for different authors. In such cases write out the first given name for each author.

The *Great Basin Naturalist* no longer abbreviates titles of periodicals and names of publishers. Include full titles as they appear on the title page, but omit initial articles. *The American Midland Naturalist* and *The Great Basin Naturalist* become, respectively, *American Midland Naturalist* and *Great Basin Naturalist*.

As a general rule, too much bibliographical information is better than too little. Unnecessary data can be deleted.

Following are examples of the most common types of bibliographic references.

- *Journals*

Arcos, M. L., A. de Vicente, M. A. Morinigo, P. Romero, and J. J. Borrego. 1988. Evaluation of several selective media for recovery of *Aeromonas hydrophila* from polluted waters. *Applied and Environmental Microbiology* 54: 2786–2792. [Only the initials of the first author are inverted; use the first author's name and "et al." for papers with seven or more authors.]

Ferguson, J. H., and C. H. Lowe. 1969. Evolutionary relationships in the *Bufo punctatus* group. *American Midland Naturalist* 81:

435–466. [Issue numbers are not included unless the journal is numbered by issue rather than by volume; the issue, supplement, or part number is then included in parentheses after the volume number:

3(6):42–57 56(suppl. 4):8–13  
2(3, pt. 4):2–5.]

Tove, M. H., and D. L. Fischer. 1991. [If the year of publication has not been determined, use "In press" in place of the date.] Recent changes in the status of wintering gull populations in Utah. *American Birds*. [Omit volume and pagination for in-press citations.]

- *Books*

Brady, N. C. 1974. *The nature and properties of soils*. 8th ed. Macmillan Publishing Co., Inc., New York. 639 pp.

Snedecor, G. W., and W. G. Cochran. 1971. *Statistical methods*. Iowa State University Press, Ames. [Repeating the state name would be redundant.]

- *Parts of books*

Smith, H. D., and C. D. Jorgensen. 1975. Reproductive biology of North American desert rodents. Pages 305–330 in I. Prakash and P. K. Ghosh, eds., *Rodents in desert environments*. Dr. W. Junk Publishers, The Hague, Netherlands.

- *Proceedings*

Schenbeck, G. L. 1982. Management of black-tailed prairie dogs on the National Grasslands. Pages 207–217 in R. M. Timm and R. J. Johnson, eds., *Proceedings of the Fifth Great Plains Wildlife Damage Control Workshop*. University of Nebraska, Lincoln.

- *Theses/Dissertations*

Cramer, K. L. 1988. Reproduction and life history patterns of *Peromyscus maniculatus* and *Perognathus* spp. in the northern Bonneville Basin, Utah. Unpublished dissertation, Utah State University, Logan. 101 pp.

- *Miscellaneous*

Tueller, P. T., C. D. Beeson, R. J. Tausch, N. E. West, and K. H. Rea. 1979. Pinyon-juniper woodlands of the Great Basin: distribution, flora, and vegetal cover. USDA Forest Service Research Paper INT-229. Intermountain Forest and Range Experiment Station, Ogden, Utah. 22 pp. [Subtitles are lowercased.]

Literature citations of reports will not be used unless adequate information has been provided for the reader to readily locate the reference.

**Appendices.** Long lists of material related only indirectly to the topic should be included in an appendix. Lists of specimens examined, for example, would be appropriate.

**Tables.** Tables are costly to typeset and therefore should be used only when they are deemed the most effective means of presenting and summarizing data. If the data can be described in one or two sentences within the text, do not present the information in a table. Tables should be self-explanatory. The title, headings, and footnotes must contain sufficient information for the reader to understand the table without referring to the text. This will be achieved if the format is clear, simple, and well organized. Also, tables of similar information presented in similar or parallel formats will aid the reader. Chapter 6 of the *CBE Style Manual* offers helpful suggestions on compiling, presenting, and condensing information in tabular formats.

All tables should be numbered sequentially. Each table must be typed on a separate sheet(s), given a complete, intelligible title, and referred to by number in the text. The title describes the topic or general trends shown in the table; it should also include species, localities, and dates of study when appropriate. Include the number of samples (for example,  $N = 24$ ) in the title or in a column heading, whichever would be more beneficial to the reader.

Make headings within tables brief and grammatically consistent with each other. Capitalize only the first word of column heads and items in stubs (row headings); do not use all uppercase letters. Footnotes to tables should be kept to a minimum. Asterisks (\*), one, two, or three, should be used for probability,  $P < .05$ ,  $.01$ , and  $.001$ , respectively. Lowercase letters are used to denote other footnotes.

Finally, a table that fits into one column of the *Great Basin Naturalist* two-column format is more likely to be printed close to its corresponding text. This, of course, is a relatively simple method of enhancing reader understanding.

**Figures.** Well-designed and prepared illustrative materials, whether photographs or black-and-white artwork, not only augment and clarify written material but also provide visual enhancement. On the other hand, poorly prepared graphics may minimize the author's or the journal's credibility.

In considering the addition of illustrations to an article, be certain the text is long enough to accommodate the artwork. In most cases two pages of typescript are required for each figure or table; three pages are preferred. When submitting an article for review, please do not send original photographs or black-and-white artwork. High-quality photocopies are adequate.

- *Photographs* (generally referred to as halftones), because of the nature of the reproduction process, are approximately two to three times as expensive to produce as line copy (black-and-white artwork). We recommend keeping halftones to a minimum. When they are included, please submit glossy originals with sharp focus, a full range of tonal values, and suitable contrast. Photographs that are slightly gray (low contrast) reproduce better than those with high contrast.

Photographs submitted with the final manuscript upon acceptance by the *Great Basin Naturalist* should be no larger than 22 x 28 cm. Ideally, the printed size will be between 50% and 100% of the original size. Smaller reductions tend to darken and lose details. Photographs can also be enlarged up to about 150% of original size without adversely affecting quality. Photomicrographs and electron micrographs should include a scale on the photograph or on an overlay.

- *Line copy* is black-and-white artwork. Prepared on a white background with black lines, it contains no grays. Graphs, diagrams, and charts fall into this category. Technical pens, flexible pens, and brushes, all used with black India ink, can produce line drawings, depending on the type of illustration desired. Technical pens will give evenly weighted lines suitable for graphs and charts. Flexible pens and brushes give smooth, tapered lines or softer, fuzzy effects, respectively.

Although line copy does not contain grays, the effect of gray areas can be achieved by using stippling, cross-hatching, or line contouring. Patterned screens with adhesive backings are also frequently used.

Line drawings should not be enlarged for publication, as enlargement reveals—and

magnifies—flaws that may not be obvious on the original. Reductions of black-and-white artwork should not exceed 50%. It is important that all lines, symbols, and letters be large enough on the original to withstand reduction and still maintain integrity and/or legibility.

- *Computer-generated graphics*, increasingly available in many institutions, are acceptable forms of black-and-white artwork as long as they are produced on laser, rather than dot-matrix, printers. The same requirements that apply to line art also apply to computer graphics.

- *General considerations for illustrations*:

1. For the sake of consistency, multiple pieces of artwork for one article or a series of articles should be prepared, if possible, by the same artist. A uniform reduction of multiple pieces will also aid consistency.

2. The general ratio of 2:3, in either a vertical or horizontal orientation, will result in artwork compatible with the *Great Basin Naturalist's* page and/or column dimensions.

3. Place necessary identifications, i.e., symbols, regression formulas, and scale bars, directly on the figure rather than in the figure legend.

4. Use symbols for data points, particularly on graphs. The most common are ○, ●, △, ▲, □, ■, ◇, ◆.

5. Identify all artwork on the back. Using a soft blue pencil, mark author and figure number, and indicate "top."

## General Style and Usage Conventions

Provide the scientific name (genus and species) of all organisms when first mentioned in the vernacular form in both abstract and text even if the name appears in the title.

Use a comma to separate the elements (words, phrases, or clauses) of a simple series of more than two. A comma precedes the "and" or "or" (e.g., blue grama, buffalograss, and needleleaf sedge).

Underline generic and specific names in text (they will be italicized in print). Do not use italics or boldface type in manuscripts.

Follow *Webster's Ninth New Collegiate Dictionary* for spelling and word-usage questions. Also, consult *Webster's Third New International Dictionary, Unabridged*.

In numbers consisting of two to four digits, run the numerals together: 1000, 3959. Use comma separators for numbers of five or more digits: 45,808. Use numerals to express any number immediately preceding an abbreviation for a standard unit of measure or expression of time: 5 g, 20 mm, 4 h. In most other situations, use words for numbers one through nine and numerals for larger numbers. However, in a series containing some numbers of 10 or more and some less than 10, use numerals for all.

Write dates with no punctuation: 16 August 1989.

Standard abbreviations are acceptable for units of measure, directions and coordinates, Latin terms (most of which no longer require italics), and statistical terms. Acronyms and other less common abbreviations should be defined when first mentioned by writing out the term and enclosing the abbreviation in parentheses following it.

Always check the most recent issue of the journal for any changes in style or format.

## A Final Word

Although we agree that adhering to established rules and maintaining a consistent style are hallmarks of good journalism, we also agree with a statement made in the preface to the University of Chicago's first (1906) edition of a *Manual of Style*:

Throughout this book it is assumed that no regulation contained therein is absolutely inviolable. . . . Each case . . . must largely be decided upon its own merits. Generally it may be stated that, where no question of good taste or good logic is involved, deference should be shown to the expressed wishes of the author.

## Acknowledgments

Portions of this manuscript were extracted from the *CBE Style Manual* (5th ed.), *The Chicago Manual of Style* (13th ed.), *Guidelines for Manuscripts for Publications of the American Society of Mammalogists*, and previously unpublished *Great Basin Naturalist* style guidelines and instructions to authors.



## INFORMATION FOR AUTHORS

The *Great Basin Naturalist* welcomes previously unpublished manuscripts pertaining to the biological natural history of western North America. Preference will be given to concise manuscripts of up to 12,000 words.

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## A HABITAT EVALUATION PROCEDURE FOR ROCKY MOUNTAIN BIGHORN SHEEP IN THE INTERMOUNTAIN WEST

Tom S. Smith<sup>1</sup>, Jerran T. Flinders<sup>1</sup>, and David S. Winn<sup>2</sup>

**ABSTRACT.**—Several habitat evaluation procedures have been developed for bighorn sheep. However, none of these procedures specifically addresses the Rocky Mountain subspecies nor analyzes both the quantity and quality of potential bighorn habitat with regard to minimum viable population (MVP) criteria. This bighorn habitat evaluation procedure combines (1) a quantitative assessment of bighorn range to determine if there are adequate quantities of resources to support an MVP of bighorn sheep, and (2) a qualitative assessment of a range to predict the probable density of bighorns the range can support. Extensive literature review, intensive bighorn research, and a modeling tool, pattern recognition (PATREC), facilitate critical analysis of proposed bighorn reintroduction sites. The resultant stepwise approach to bighorn habitat evaluation enhances the ability of wildlife biologists to make timely and accurate bighorn habitat assessments.

**Key words:** *Habitat evaluation procedure, geographic information system, pattern recognition, minimum viable population, bighorn sheep, *Ovis canadensis canadensis*.*

The precipitous decline of Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) after arrival of American settlers has been well documented (Buechner 1960). As early as 1880, some bighorn herds had been extirpated, while others suffered sharp reductions. Even recently, Jahn and Trefethen (1978) warned that without more effective management, an additional loss of 8% of bighorn sheep could be expected over the next 25 years.

The inability to successfully restore bighorn to former ranges in the western United States results in part from habitat deficiencies that hamper herd growth and persistence. For example, Utah's reintroduction program has not succeeded in restoring Rocky Mountain bighorn to former ranges (Smith et al. 1988). Transplanted sheep have failed to increase,

and the current statewide total is approximately equal to the number of transplant animals released (Smith et al. 1988). Reasons for this include: (1) inadequate quantities of available range, (2) severe competition with other ungulates, (3) contact with domestic livestock, (4) improper juxtaposition of key habitat components, (5) inadequate quantities of one or more critical seasonal ranges, and (6) excessive human harassment. More rigorous assessments of proposed reintroduction areas would enhance program success. This habitat evaluation procedure (HEP) is an effort to provide wildlife professionals with a better tool for assessing bighorn habitat quality.

Although several bighorn habitat evaluation procedures have been developed (Ferrer and Bradley 1970, Merritt 1974, Golden and Tsukamoto 1980, Grunigen 1980, Hansen

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1980, Wilson et al. 1980, Holl 1982, and Armentrout and Brigham 1988), this HEP has been developed because (1) a Rocky Mountain bighorn sheep HEP is nonexistent and (2) none of the above procedures critically examines actual, or proposed, bighorn ranges for the minimum area necessary to support at least a minimum viable population (MVP) of bighorn sheep. An MVP has been defined by Shaffer (1983) as the smallest isolated population having at least a 95% probability of surviving at least 100 years. Though precise MVP estimates for bighorn sheep are not available, Berger (1990) studied 122 bighorn sheep populations in southwestern United States and found that 100% of the bighorn populations with fewer than 50 individuals went extinct within 50 years. Berger also reported that bighorn populations with more than 100 sheep had persisted for 70 or more years. Consequently, he concluded that 50 bighorn sheep did not constitute a minimum viable population and that managers should strive for herds numbering more than 100 (J. Berger, University of Nevada, personal communications). Additionally, Geist (1975) and others (Sands 1976, Van Dyke et al. 1983) have suggested that wildlife managers should maintain herds of at least 125 individuals if the herds are to survive and persist. Based on this information, it is suggested that 125 individuals represent a current "best estimate" MVP (termed MVPE hereafter) for bighorn sheep populations. Because restoration efforts should strive to establish populations with long-term persistence, this bighorn habitat evaluation procedure assesses the ability of a proposed site to support at least 125 bighorn sheep. This requirement can be relaxed if a reintroduction site is situated so that exchange with nearby herds is expected. In the Mojave Desert of southern California and Nevada, Schwartz et al. (1986) report a stable metapopulation of desert bighorns consisting of 23 subpopulations, many of which fall far short of the 125 MVP estimate. However, due to the close proximity of individual herds and the presence of migration corridors, rams regularly travel between them and maintain gene flow, thereby alleviating the genetics problems which insular, nonmigratory populations face. Therefore, if other populations are close and have access to the reintroduced population, the problem of meeting MVPE criteria

may be alleviated. Regarding interherd migrations, Schwartz et al. (1986) cite distances that bighorn have been observed traveling between herds in southern California. Extrapolation of these data to more forested regions should be done with discretion.

The importance of thorough site evaluation prior to bighorn reintroduction is illustrated by research from Bear Mountain of the Flaming Gorge National Recreation Area in north-eastern Utah. Cursorial evaluation of the Bear Mountain transplant area suggests that about 6900 ha of habitat area is available to bighorn sheep. However, when one uses this HEP to identify how much suitable habitat actually exists, only 3800 ha (a 55% reduction) meets the criteria for suitable bighorn habitat (Smith and Flinders 1991). Subsequent research conducted at Bear Mountain verifies the fact that less than half the area is acceptable and usable by bighorn (Smith and Flinders 1991). Hence, even though considered an excellent site by many, Bear Mountain barely meets the minimum space requirements for an MVPE of 125 bighorn sheep.

#### BIGHORN HEP CAPABILITIES

This bighorn HEP (1) estimates the quantity and quality of occupied, or proposed, bighorn ranges, (2) predicts a site's ability to support at least an MVPE of bighorn sheep, (3) identifies population limiting factors, (4) enables estimation of the effects of management activities on bighorn habitat, (5) assists identification of cost-effective habitat management strategies, and (6) allows use of geographic information systems (GIS) technology for habitat evaluations (Fig. 1). This HEP may be used to evaluate proposed transplant sites or currently occupied ranges.

#### BIGHORN HEP OVERVIEW

This HEP performs two analyses: estimation of habitat quantity (Part 1) and quality (Part 2). The combination of these two habitat characteristics determines range carrying capacity. Part 1 uses questions regarding bighorn habitat requirements to define probable range area and boundaries. Part 2 employs pattern recognition (PATREC) to assess range quality.

# ROCKY MOUNTAIN BIGHORN SHEEP HABITAT EVALUATION PROCEDURE AN OVERVIEW

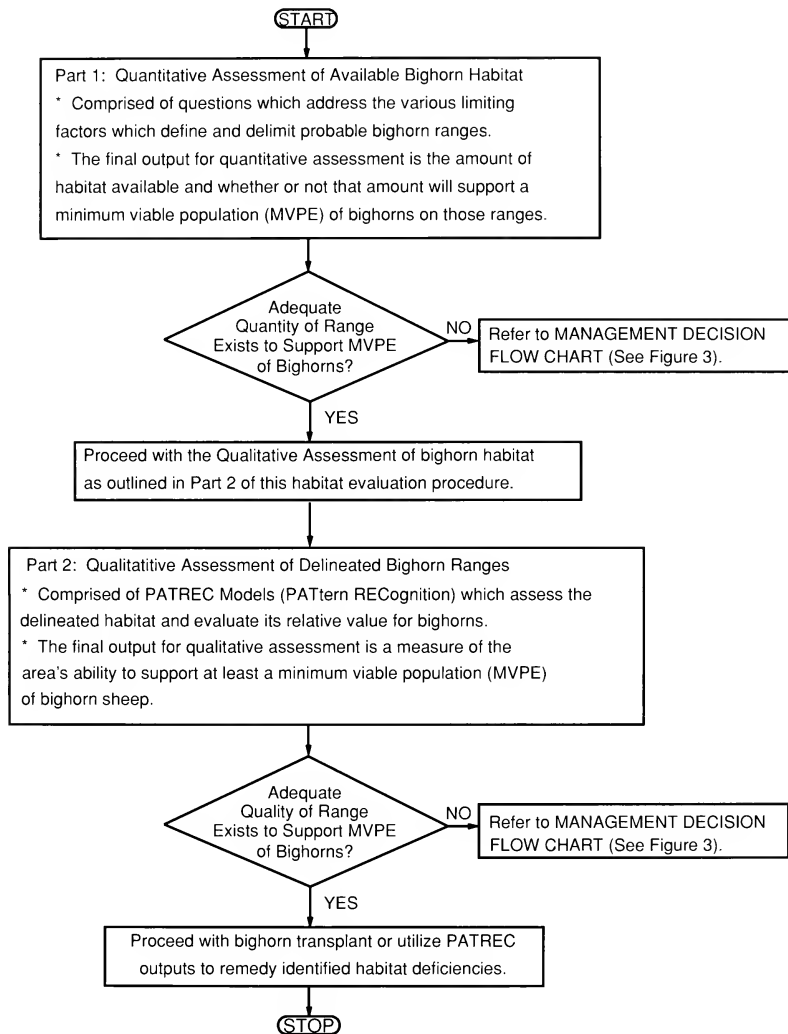


Fig. 1. An overview of the Bighorn Habitat Evaluation Procedure.

Bighorn sheep movements are restricted by both intrinsic (behavioral and physical) and extrinsic factors (fences, geographic barriers, etc.). Because bighorn response to habitat variables is reasonably predictable, it is possible to estimate bighorn range size. Although bighorn will occasionally ignore normal barriers to movement, managers should not expect disjunct portions of range, separated by barriers, to contribute significantly to bighorn ranges. A proposed bighorn reintroduction site comprising scattered range segments, crisscrossed with barriers, with key habitat components ineffectively juxtaposed or absent, would ultimately fail to sustain a herd for long. Part 1 presents the normally restrictive barriers and assists in identifying the probable range boundaries, maximum range area, and juxtaposition of key habitat components. Part 1 focuses on critical aspects of bighorn habitat and helps managers determine a site's ability to provide suitable bighorn habitat in the amount needed to support an MVPE of sheep.

Bighorn range quality results from the interaction of many abiotic and biotic characteristics. These interactions create patterns of habitat suitability. The PATREC approach captures in simple mathematical form the process by which most biologists intuitively assess habitat suitability patterns (Grubb 1988). To date, PATREC models have been applied to a variety of wildlife, including Bald Eagles (Grubb 1988), deer (Kling 1980), Sage Grouse (Evans 1983), and bighorn sheep (Holl 1982). For a thorough description of PATREC, see Kling (1980) and Williams et al. (1977). Before proceeding with Part 2 of this HEP, review of PATREC is essential. Particularly helpful is the User's Guide to PATREC for Habitat Evaluation (Kling 1980).

Although most rigorous evaluation of habitat occurs when Parts 1 and 2 are applied, it is not essential that both be used. Part 1 is the key component and cannot be omitted for it defines the ranges that Part 2 analyzes. When insufficient range quantity or irreparable habitat problems have been identified through application of Part 1, site analysis need not proceed. Application of Part 2 requires a more detailed database. It may be used to identify specific weaknesses of a reintroduction site and to determine which

remedial approach will yield greatest benefits. We believe that prior to reintroduction of bighorns, rigorous site analysis based on Part 1 alone would greatly enhance the success of many reintroduction efforts.

## METHODS

Stepwise discussion of the HEP follows and corresponds to numbered steps in Figure 2.

### Part 1

#### Quantitative Assessment of Available Bighorn Habitat

Sequential questions enable the user to (1) determine the probable range boundaries for an actual, or proposed, bighorn herd, (2) analyze the total area of that range in terms of MVPE criteria, (3) determine if adequate quantities of winter, lambing, and summer ranges exist, and (4) decide if the juxtaposition of habitat components is adequate.

**STEP 1.**—Any portion of range that might allow contact between bighorns and their exotic relatives, including domestic sheep and goats, should be excluded from consideration.

Recent research has verified the incompatibility of domestic sheep, goats, and bighorn sheep on the same ranges (Foreyt 1990). Exotic relatives of bighorn sheep, including mouflon sheep (*Ovis ammon musimon*), barbary sheep (*Ammotragus lervia*), and ibex (*Capra ibex*), are sources of disease, competition, and genetic pollution for bighorn sheep (Geist 1988). Domestic sheep (and goats in one instance) have been implicated as the disease source responsible for several recent bighorn sheep catastrophic die-offs (Jessup 1981, Goodson 1982, Capurro 1988, Coggins 1988). Bighorn sheep and mouflon sheep readily cross and produce viable offspring. Impure, genetically polluted bighorns have no historic, conservation, or scenic value. Although minimum distances for separation of bighorn and exotics, including domestic sheep, have been suggested (Holl and Bleich 1983, Armentrout and Brigham 1988, Coggins 1988), the potentially catastrophic consequences of exotic-bighorn interactions justify a policy of absolute separation. If separation is not possible, the area should not be considered potential bighorn range until exotics are



removed. Ranges recently vacated of exotics require no resting period before bighorn transplanting because the pneumophillic diseases that precipitate die-offs are transmitted by direct contact only.

STEPS 2 AND 3.—Estimate the probable range boundaries of available bighorn habitat.

Steps 2 and 3 determine whether bighorns are already present on the site and, if so, their range boundaries. When the bighorn herd is established and approximate range boundaries known, steps 4–8 can be disregarded, since their role is to estimate the probable extent of bighorn ranges.

STEP 4.—Delineate and buffer core bighorn habitat areas.

All bighorn habitat is dependent upon the presence and extent of escape terrain areas. Escape terrain comprises slopes greater than 60% (about 27°) that have occasional rock outcroppings whereon bighorn can outmaneuver predators and find secure bedding areas. For a more thorough discussion of escape terrain, see Van Dyke et al. (1983). Because escape terrain provides antipredator protection, bedding and lambing areas, and areas of lesser snowpack, it has been identified as the most critical habitat component for bighorns (Buechner 1960, Ferrier and Bradley 1970, Geist 1971, Wilson et al. 1980, Van Dyke et al. 1983). Specialized for leaping and climbing rather than for running on flat terrain (Geist 1971), bighorns are tied to escape terrain and seldom venture far from it (McCann 1956, Oldemeyer et al. 1971, Brown 1974, Van Dyke et al. 1983, Hansen 1984, Gionfriddo and Krausman 1986). On Bear Mountain, 95% of all bighorn activity occurred within 300 m of escape terrain (Smith and Flinders 1991). Therefore, areas not within 300 m of escape terrain should be excluded when evaluating bighorn ranges.

Occasionally, a segment of range is bounded on two or more sides by escape terrain. If the range between escape terrain areas is 1000 m wide or less, the entire area should be included as potential bighorn habitat. In such situations, bighorn are apparently willing to roam farther from safety (up to 500 m) because of the increase in escape route options (Van Dyke et al. 1983).

STEP 5.—Identify additional restrictions for range boundary determinations including natural and man-made barriers to bighorn movement.

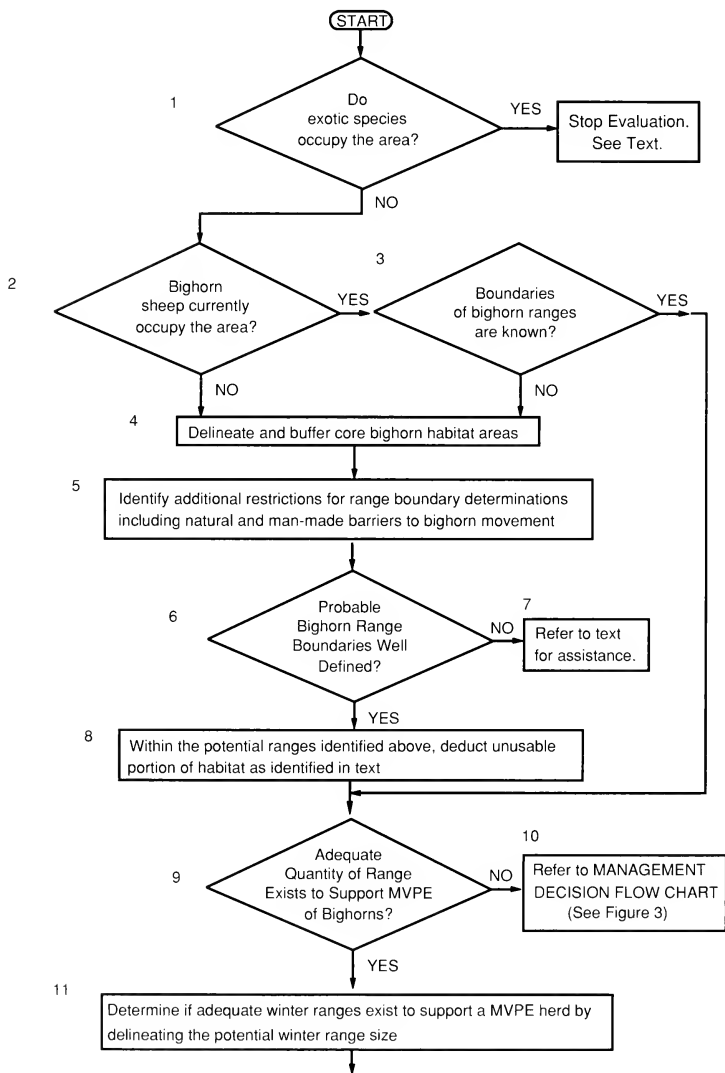
#### A. Natural barriers

1. *Water: swift and/or wide rivers and lakes.* Although Cowan (1940) occasionally observed bighorn swimming, water has been noted elsewhere to effectively delimit bighorn ranges (Graham 1980, Wilson et al. 1980, Smith and Flinders 1991). Rivers and lakes break range continuity and are commonly barriers to bighorn movements. Consequently, because bighorn herds rarely inhabit both sides of a canyon when a major river is present, managers should consider one side, but not both sides, of a continuous water body as bighorn range.

2. *Dense vegetation.* Smith and Flinders (1991), Brundige and McCabe (1986), Risenhoover and Bailey (1980), Wilson et al. (1980), McCann (1956), Cowan (1940) and others have stated that bighorn sheep hesitate crossing even narrow tracts of dense vegetation, particularly timber. Aversion to low visibility, likely a predator-avoidance strategy, restricts bighorn movements. Dense timber, thick shrubs, and lush herbaceous tracts often form impassable barriers to bighorns. For this reason, low-visibility areas at least 100 m wide should be considered movement barriers to bighorn sheep. Because these areas can restrain bighorn from utilizing more suitable terrain beyond, they need to be identified. Smith and Flinders (1991) present methodology for determining the horizontal visibility of an area. They found that areas with less than 80% horizontal visibility were little used by bighorns, regardless of their other qualities (e.g., distance to cliffs, herbaceous plant production, etc.).

3. *Cliffs: continuous, nontraversable cliff complexes.* Although bighorn rely heavily on cliffs, some cliff complexes do not qualify as escape terrain, but rather function as barriers to movement. Sheer, vertical cliffs, lacking negotiable terrain, can limit bighorn movements and range size. Of particular concern are continuous bands of sheer cliffs because they may isolate other

## PART 1: QUANTITATIVE HABITAT ASSESSMENT FLOW DIAGRAM



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Fig. 2. Part 1: Quantitative Habitat Assessment flow diagram.

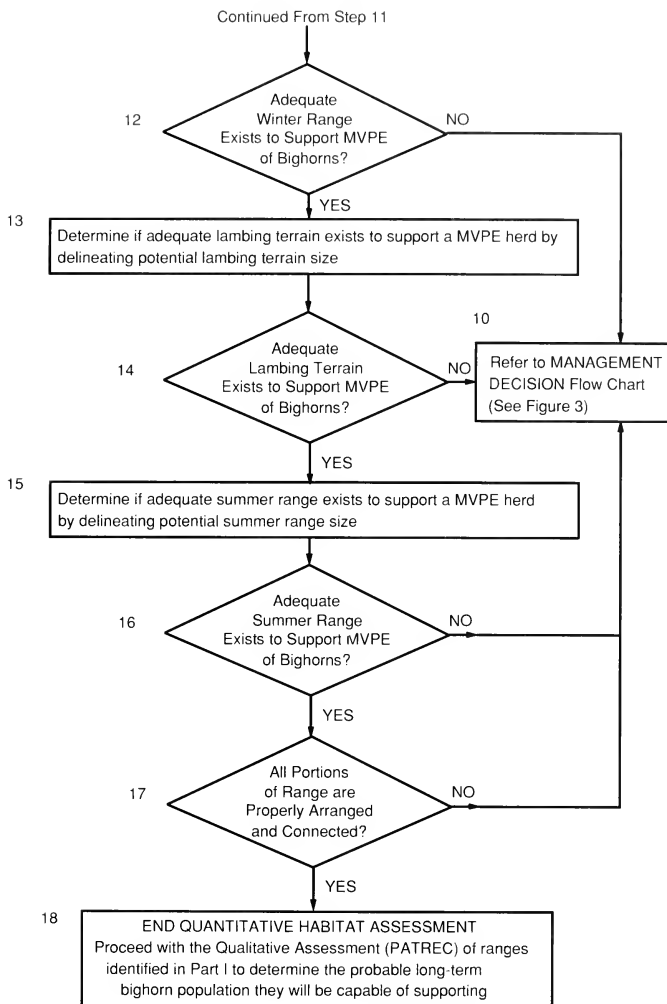


Fig. 2 continued.

wise useful areas from the rest of the range. As a rule of thumb, although bighorn are adept climbers, if a human cannot negotiate a particular cliff area, bighorn should not be expected to do so either.

4. *Valleys or plateaus.* If valleys separating areas of escape terrain are wider than

1000 m, they may act as barriers to bighorn movements. Similarly, plateaus separating escape terrain areas by more than 1000 m should be considered range boundary delimiters. When confronted with these barriers, bighorn will attempt to circumvent them if possible. However,

if long and continuous, these barriers may totally isolate ranges that otherwise would have value to the herd. In such cases these areas must not be included as bighorn range.

#### B. Man-made barriers

1. *Water: canals, reservoirs, aqueducts.* Linear waterways generally tend to impede bighorn movements. Concrete-lined canal systems, reservoir impoundments, and aqueduct structures can create impassable barriers and bighorn death traps (Graham 1980). As a general rule, these structures should be considered range delimiters, and bighorn sheep should not be expected to routinely cross them to access other portions of potential range (Slezniak 1963).

2. *Impassable fencing.* Fencing can restrict bighorn movements and result in mortality, particularly for rams whose horns may become entangled. Helvie (1971) presents a useful discussion of the types of fencing that limit bighorn movements. If barrier fencing exists on proposed bighorn ranges, boundaries should be drawn along them.

3. *Major highways and high-use roadways.* Besides the fencing often associated with major highways and high-use roadways (interstate, federal, or state highways), associated human activity often deters bighorn from regularly crossing these areas (Ferrier 1974, McQuivey 1978, Risenhoover 1981, Van Dyke et al. 1983). The impact of highways must be carefully evaluated, and those restricting bighorn movements should be considered boundaries of contiguous bighorn ranges.

4. *Centers of human activity.* Airports, dwellings, campgrounds, and ski resorts are examples of centers of human activity that frequently invade bighorn ranges. As such, they represent potential range delimiters to bighorn sheep, particularly when aligned in linear fashion. Each occurrence must be evaluated individually and range boundaries drawn accordingly.

STEPS 6 AND 7.—Determine whether probable bighorn range boundaries are well defined.

After identifying the above range-delimiting characteristics, managers should roughly define the boundaries of a proposed bighorn

sheep release site. If this is not yet possible, given the data to this point, the following additional range constraints should further define range boundaries.

STEP 8.—Deduct unusable portions of habitat from within identified potential bighorn ranges, as follows:

A. Areas beyond 3.2 km from water sources. McQuivey (1978) noted that 85% of bighorn activity occurred within 3.2 km of water. Brundige and McCabe (1986) reported that all bighorn in Custer State Park, South Dakota, remained within 1 km of watering sources. Van Dyke et al. (1983) concluded that water sources farther than 0.5 km from escape terrain received only limited use. Sands (1976) suggested that optimal spacing between water sources was 1.6 km. We believe that critical bighorn ranges will occur within 3.2 km of usable water sources; hence, areas beyond 3.2 km should be excluded from consideration as core-use ranges. It is important to note that seeps, springs, perennial snow patches, streams, rivers, ponds, lakes, and reservoirs all qualify as bighorn watering sources. However, excessive human activity around water resources (Jorgensen 1974), water heavily used by livestock and ungulate wildlife (Welles and Welles 1961, Van Dyke et al. 1983), alkaline waters (Jones et al. 1957), and water sources surrounded by dense vegetation should not be considered usable by bighorn. Schmidt (Colorado Division of Wildlife, personal communications) noted that guzzlers are generally avoided by Rocky Mountain bighorn sheep on Colorado ranges. Having observed the same phenomenon in northeastern Utah, Smith and Flinders (1991) recommended that guzzlers be fitted with remote watering troughs for bighorns to use. In the cooler, temperate regions where the Rocky Mountain subspecies normally occur, water is rarely a limiting factor, unlike areas of desert bighorn habitat to the south. However, where water resources are limited, they must be considered as effective range delimiters.

B. A 100-m-wide buffer should be placed around areas of low to moderate human use. Areas typically receiving low to moderate human activity include some trails, roads, dwellings, and campgrounds. Many have noted the negative effect of human activities on bighorn sheep (Dunaway 1971, Light

1971, Hicks and Elder 1979, Giofriddo and Krausman 1986). Light (1971) defined "light use" on back-country trails as 0–100 visitors a year, "moderate use" as 100–500 visitors, and "high use" as over 500 visitors a year. He reported that low- to moderate-intensity activity displaced bighorn activity up to 100 m from the source. For this reason these areas should be buffered accordingly.

C. A 150-m-wide buffer around areas of high-intensity human use. Areas typical of high-intensity human activity include some airports, mines, tramways, campgrounds, ski resorts, and heliports. A 150-m-wide buffer beyond the periphery of such areas should be excluded from consideration as bighorn range.

D. All plant communities typified by horizontal visibility of less than 80%. Research by Smith and Flinders (1991), Brundige and McCabe (1986), Risenhoover (1981), and Risenhoover and Bailey (1980) indicates that bighorn avoid areas of poor visibility. Smith and Flinders (1991), using a gridded, meter-square target, measured percentage of target visible in various habitat types and found that bighorn avoid most areas in which horizontal visibility is less than 80%. Conifers with dense understory, brushy meadows, and many riparian areas are of such poor visibility as to preclude bighorn activity. As a rule of thumb, shrub communities with a mean height greater than 0.5 m, riparian areas with a dense understory, heavily forested areas, and more open timber stands with an understory greater than 0.5 m in height will be avoided by bighorn sheep. All such areas should be excluded from the potential bighorn range.

E. Portions of range seasonally occupied by concentrations of elk or cattle. If portions of potential bighorn range will have elk or cattle present concurrently with bighorn, such areas should be excluded from potential bighorn range. Aside from direct competition for forage (McCann 1956, Demarchi 1965, Oldemeyer et al. 1971, Morgan 1973, McQuivey 1978, Estes 1979, Van Dyke et al. 1983), disease transmission (Wishart 1978, Lawson and Johnson 1980, Van Dyke et al. 1983, De Forge 1988, Jessup 1981) and social intolerance (Wilson 1975, McQuivey 1978, Law-

son and Johnson 1980, King and Workman 1984) are adequate reasons for excluding elk or cattle ranges from consideration as critical bighorn use areas. That these large ungulates often totally displace bighorn has been well documented; therefore, individual conflicts must be carefully evaluated. Whenever a proposed site will considerably overlap the range of elk, cattle, or perhaps even bison, careful consideration should be given the potential for competition and displacement.

After the areas identified in 8A to 8E have been deducted from potential range defined in steps 4–5, the remaining area represents range suitable for bighorn sheep if introduced into the area. Because transplanted bighorns often establish their home ranges around the release site (Geist 1971, Brundige and McCabe 1986), they can be expected to remain within a 15-mile radius of it once they have adjusted to the area, usually within a year of the release. This may help to further delimit probable ranges in case boundaries are yet ill defined.

STEP 9.—Ascertain whether adequate range exists to support an MVPE of bighorns.

Van Dyke et al. (1983) suggested that 1.9 bighorns per  $\text{km}^2$  (5 per  $\text{mi}^2$ ), averaged over an entire range, would represent a maximum density for ranges in the Great Basin portion of southeastern Oregon. If this represents a reasonable estimate for other sites in the Intermountain West, a minimum of 65  $\text{km}^2$  (25  $\text{mi}^2$ ) of habitat would be required to support 125 bighorn sheep. However, densities ranging from less than 0.4 bighorn per  $\text{km}^2$  (1 per  $\text{mi}^2$ ) (McQuivey 1978) to over 27 per  $\text{km}^2$  (70 per  $\text{mi}^2$ ) (Demarchi 1965) have been reported. Unfortunately, all reported bighorn densities appear to have been calculated for areas that included both usable and unusable portions of range. This underestimates true bighorn densities within occupied areas. For example, McQuivey (1978) calculated bighorn densities of several Nevada herds using polygons that encircled all observed bighorn sightings. As a result, he included portions of unsuitable ranges with the suitable, thereby overestimating true range size. Demarchi (1965) reported that although the mean density of bighorn for the Chilcotin River area was 4.7 per  $\text{km}^2$  (12.1 per  $\text{mi}^2$ ), key grassland areas supported as many as 27 bighorn per

km<sup>2</sup> (70.4 per mi<sup>2</sup>). In light of these and other research reports, we suggest the following guidelines:

(1) The ranges defined through step 5 (unsuitable portions not yet withdrawn) should not be expected to support more than an average of 3.9 bighorn per km<sup>2</sup> (10 per mi<sup>2</sup>). This means that there must be at least 32 km<sup>2</sup> (12.5 mi<sup>2</sup>) of habitat identified to the level in step 5 to support at least an MVPE of bighorn sheep.

(2) The ranges remaining after step 8 has been applied (unsuitable portions of range deducted) should not be expected to support more than 7.7 bighorns per km<sup>2</sup> (20 per mi<sup>2</sup>). Hence, there must be at least 17 km<sup>2</sup> (6.5 mi<sup>2</sup>) of core habitat remaining in order to support at least an MVPE of bighorn sheep.

(3) Proposed ranges with an abundance of grassland can be expected to support more sheep than the above estimates, whereas those with less grassland should be expected to support fewer sheep. However, if range area estimates are not within reasonable boundaries of those recommended above, the site may not warrant a bighorn transplant.

Step 9 instructs wildlife biologists to compare the evaluation area against the minimum range area criteria necessary to support at least 125 sheep. Although these minimum area values are rough estimates, they do represent reasonable minimums and therefore should be seriously considered when potential bighorn reintroduction sites are evaluated. If a proposed release site is so restricted in size that these suggested area minimums cannot be met, the site should not be considered a good candidate for a future release of bighorn sheep. However, as mentioned earlier, another option exists: creating a metapopulation comprising subpopulations of less than 125 bighorn as long as bighorn movements can occur between them.

STEP 10.—Refer to the management decision flow chart.

When a proposed range appears inadequate to support the suggested MVPE of bighorn sheep, the user is referred to the Management Decision Flow Diagram (see Fig. 3, adapted from Holl and Bleich 1982). Figure 3 suggests alternative actions to resolve the problem.

STEP 11.—Determine if adequate winter range exists to support an MVPE herd by delineating the potential winter range size.

Even if a site is satisfactory in all other respects, when winter ranges are inadequate or lacking, a transplant will fail. Indeed, some transplant failures in Utah have been due, in part, to inadequate winter ranges (Smith et al. 1988). Winter ranges are delineated as follows:

A. Select all areas within 300 m of escape terrain. Areas of up to 1000 m from escape terrain may also be included if multiple escape routes exist, as described in step 4.

B. Within areas selected in step 11A, identify sites receiving less than 25 cm of snowpack. Heavy snow accumulations render potential winter range areas unusable (McCann 1956, Tilton and Willard 1982, Johnson 1983, Smith and Flinders 1991). Research in northeastern Utah indicated that bighorns abandoned ranges when snowpack exceeded 25 cm.

C. Of those areas selected in step 11B, exclude all escape terrain without southern exposures (SW-S-SE). Studies addressing winter range requirements have consistently noted that key winter ranges are typified by southern exposures (Shannon et al. 1975, Hudson et al. 1976, Stelfox 1976, Johnson 1983, Smith and Flinders 1991). Identify those areas.

D. Determine the total area of potential winter range from those areas that fit the criteria in steps 11A–C. Add the areas and calculate the total area of probable winter range available.

STEP 12.—Verify whether adequate winter range exists to support an MVPE of bighorns.

Step 12, like step 9, alerts site evaluators to critical winter range deficiencies. How much winter range is adequate? Coggins (1980) reported winter range densities of 31 bighorns per km<sup>2</sup> (80 per mi<sup>2</sup>) for the Lostine River herd of northeast Oregon. Woodgerd (1964) and Blood (1963) reported winter range densities of 19–23 bighorns per km<sup>2</sup> (50 to 60 per mi<sup>2</sup>). Wehausen (1983) reported winter densities averaging 20 bighorns per km<sup>2</sup> (52 per mi<sup>2</sup>) for the Mt. Baxter herd. High-quality portions of the same winter ranges supported nearly double the average value, or 37 big-

## BIGHORN SHEEP MANAGEMENT DECISION FLOW DIAGRAM

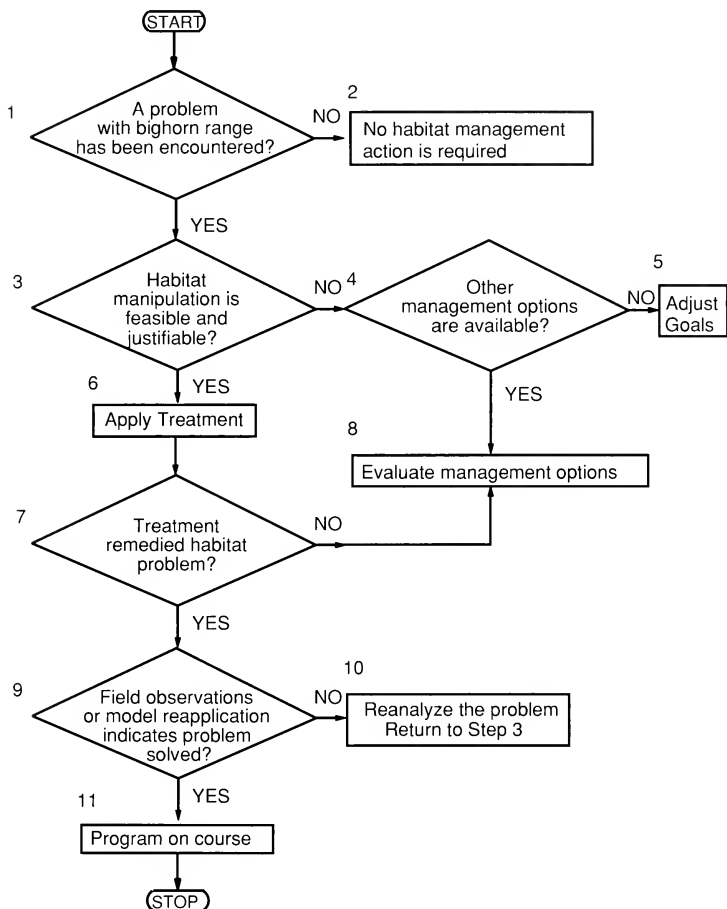


Fig. 3. Bighorn Sheep Management Decision flow diagram.

horn per km<sup>2</sup> (97 per mi<sup>2</sup>). In light of these and other reports, we believe that winter ranges should not be expected to support more than 20 bighorns per km<sup>2</sup> (about 50 per mi<sup>2</sup>). Therefore, to sustain an MVPE of

125 bighorns, a particular range must have at least 6.5 km<sup>2</sup> (2.5 mi<sup>2</sup>) of available winter range. If an analysis of this step reveals inadequate winter range, then refer to the Management Decision Flow Diagram (Fig. 3),

which recommends alternative actions to resolve the problem.

**STEP 13.**—Determine if adequate lambing terrain exists to support an MVPE herd by delineating potential lambing terrain size.

In some instances, inadequate quantities of lambing terrain have been cited as the ultimate factor controlling bighorn herd size (Hansen 1982). The importance of adequate amounts of suitable lambing terrain cannot be overemphasized, as lamb survival and recruitment can have a greater effect upon transplant success than any other factor of herd population dynamics (Smith and Flinders 1991). Lambing terrain has been defined as the most precipitous, rugged, and remote areas of the bighorn ranges; in addition, these areas are near forage and have dry, southern exposures (Geist 1971, Van Dyke et al. 1983). Identify and select those areas meeting the following criteria:

A. Select all areas identified as potential escape terrain. These areas have already been identified in step 4.

B. Of areas identified in step 13A, select all southerly aspects. Lambing areas most commonly have southern exposures (Geist 1971, Van Dyke et al. 1983, Smith and Flinders 1991). Smith and Flinders (1991) indicated that most lambing areas fall within aspects from 90° to 270°. Select escape terrain areas that fit these aspect criteria.

C. Of areas identified in step 13B, select those typified by horizontal visibility of greater than 80%. Refer to step 8D for a discussion and description of the concept of horizontal visibility. Visibility is measured along predator-approach pathways, not into, or over, cliffs. Because bighorns consistently select against areas having poor visibility, only areas of good visibility are considered suitable for lambing.

D. Of areas identified in step 13C, select only portions within 1000 m of usable water sources. Because of the water demands of lactating ewes, and the inability of young lambs to travel far, water sources need to be within, or adjacent to, lambing areas (Van Dyke et al. 1983). Smith and Flinders (1991) suggest a maximum distance from water of 675 m. Beyond that distance use of lambing terrain

declines rapidly. For purposes of this evaluation, areas beyond 1000 m from water should not be considered usable for lambing.

E. Deduct from areas identified in step 12D habitats that are smaller than 2 ha (5 acres). Van Dyke et al. (1983) suggest that ewes select rugged cliffs that are greater than 2 ha for lambing. They did say, however, that if an area is remote, extremely rugged, and free of harassment, parcels as small as 1 ha (2.5 acres) receive occasional use. For purposes of this assessment, areas less than 2 ha should not be considered potential lambing terrain unless extremely rugged and isolated.

F. Determine the total hectares of potential lambing terrain from areas meeting the criteria of steps 13A–E. Sum the areas of probable lambing terrain identified in steps 13A–E.

**STEP 14.**—Decide if adequate lambing terrain exists to support an MVPE of bighorns.

As in steps 9 and 12, step 14 warns biologists of proposed release sites that are deficient in critical lambing terrain. Although reported bighorn age/sex ratios vary widely, an MVPE population of 125 should have approximately 50–60 breeding ewes (inferred from data from Buechner 1960, Oldemeyer et al. 1971, Holl 1982, McQuivey 1978, Smith et al. 1988). Holl (1982) showed that 60 ha of escape terrain is needed to support 10 lambing ewes. If this assumption is true for bighorn in the Intermountain West, a minimum of 300–360 ha (1.2–1.4 mi<sup>2</sup>) of suitable escape terrain would be required to support the 50–60 ewes during lambing. It is recommended that at least 360 ha (1.4 mi<sup>2</sup>) of escape terrain, as classified in steps 13A–F, be available for lambing. If the available lambing terrain is less than the recommended baseline value of 360 acres, refer to the Management Decision Flow Diagram for suggested alternative actions.

**STEP 15.**—Determine if adequate summer range exists to support an MVPE herd by delineating potential summer range areas.

In some instances, inadequate quantities of summer range have been cited as the key factor limiting bighorn herd size (Arnett et al. 1990). Summer ranges, as defined here, refer to those areas utilized by all bighorns not involved in lambing activities from May



through August. This nonlambing group includes the mature ram cohort (four-year-olds and older), yearlings, two-year-old ewes, young rams up to three years of age, and barren ewes. While these sheep are occupying summer ranges, ewes inhabit lambing ranges. Identify and select those areas meeting the following criteria:

A. Delimit all buffer areas (300 m) adjacent to, but not including, escape terrain. These areas were identified in step 4. They include areas having slopes less than 60%.

B. Of areas identified in step 15A, select those having horizontal visibility greater than 80%. Refer to step 8D for a discussion of the concept of horizontal visibility. Bighorns avoid areas of poor visibility; thus, areas of high visibility should be selected as suitable for summer range.

C. Of areas identified in step 15B, select only portions within 3.2 km of water. As discussed in step 8A, it is assumed that ranges farther than 3.2 km from water do not constitute key areas for sheep and are thus withdrawn from consideration as summer range.

D. Determine the total hectares of potential summer range from areas meeting the criteria in steps 15A–C. Calculate the total area of probable summer ranges as identified in steps 15A–C.

STEP 16.—Insure that adequate summer range exists to support an MVPE of bighorns.

As with steps 9, 12, and 14, step 16 alerts biologists to sites deficient in summer range. As discussed above, an MVPE population of 125 would have approximately 50–60 breeding ewes at most. This leaves approximately 65–75 nonbreeding bighorn to occupy summer ranges. In step 9 it was suggested that ranges would probably not support more than 7.7 bighorns per  $\text{km}^2$  (20 per  $\text{mi}^2$ ). Therefore to support 65–75 bighorns on summer range, at least 8.4–9.7  $\text{km}^2$  (3.2–3.6  $\text{mi}^2$ ) of summer range should be available. If available summer rangelands are significantly less than these recommended areas, consult the Management Decision Flow Diagram for alternatives.

STEP 17.—Determine whether all portions of range are properly arranged and connected.

The quantity, quality, and juxtaposition of forage, water, and escape terrain interact to determine bighorn population size and health (Hansen 1982, Van Dyke et al. 1983). In optimum bighorn habitats, water sources and escape terrain are interspersed throughout forage areas. This interspersed promotes herd dispersal and protects the range against overuse of plant communities. If escape terrain, water, and forage are not intermixed throughout the bighorn range, the situation is not ideal. If other critical elements of bighorn ranges are deficient (total area available, area of winter range, lambing terrain, or summer range), the area being evaluated may not be suitable for bighorn reintroduction unless management actions can correct the problems.

STEP 18.—This concludes Part 1 of the Rocky Mountain Bighorn Sheep Habitat Evaluation Procedure. If insurmountable habitat problems were encountered in Part 1, further evaluation (application of Part 2) of the proposed bighorn sheep ranges is unnecessary. If, however, the ranges appear to satisfy the foregoing minimum criteria, habitat quality estimation may be desirable. For range quality analysis proceed to Part 2 of this HEP.

## Part 2

### Qualitative Assessment of Available Bighorn Habitat—PATREC

Once bighorn range boundaries have been determined, an estimate of range quality may follow. A range that is capable of supporting an MVPE of bighorns must fulfill the continuously changing needs of herd members (Holl and Bleich 1982). Because varying seasonal demands accompany each bighorn cohort (ram and ewe superclass), three separate PATREC models have been constructed: (1) a ram spring-summer model, (2) a ewe spring-summer (lambing period) model, and (3) an all bighorn fall-winter model (Tables 1–3). These three models permit analysis of the habitat from the unique perspective of each group. Because Bear Mountain ram and ewe cohorts did not sufficiently segregate after the fall rut season, a single model was used to analyze habitat.

A map that estimates bighorn density for the site can be constructed from PATREC models. This density map presents changing

TABLE 1. Habitat evaluation model (PATREC) for spring-summer bighorn ram ranges of northeastern Utah [prior probabilities P(H) = High = .30; P(L) = Low = .70].

Habitat attributes	Conditional probabilities	
	High	Low
TERRAIN		
1. The area is greater than, or equal to, 7250' elevation.	0.78	0.30
2. The average slope of the area is:		
a. less than 6°.	0.67	0.20
b. 6° to 15°.	0.22	0.20
c. greater than 15°.	0.11	0.60
3. The area is not within escape terrain.	0.59	0.40
VEGETATION		
4a. The area has horizontal visibility greater than, or equal to, 90%.	0.67	0.10
OR		
4b. Tree canopy cover is less than, or equal to, 10%.	0.59	0.60
OR		
4c. Average shrub height is less than, or equal to, 0.5 meters.	0.67	0.40
5. Grass, forb, and shrub cover is greater than, or equal to, 15%.	0.67	0.10
6. The area supports greater than, or equal to, 250 kg per hectare (dry weight) of grasses and forbs.	0.78	0.33

habitat quality across the site, indicating areas of higher and lesser value to sheep. This implies that once bighorn introduced to the area reach a carrying capacity equilibrium, PATREC predictions will approximate actual density distributions. There has been debate about the use of density as an indicator of habitat quality (Van Horne 1983, Maurer 1986). However, it is believed that bighorn sheep respond numerically to habitat quality such that increasing numbers of animals occupy sites of increasing quality (Smith and Flinders 1991).

It is important to note that Part 2 of this procedure has been specifically developed with data obtained from the Bear Mountain bighorn herd. Managers should recognize that some habitat-related questions may not be applicable to sites other than the Bear Mountain area. However, because each specific PATREC question addresses a habitat variable important to bighorn sheep, managers should attempt to obtain accurate values

TABLE 2. Habitat evaluation model (PATREC) for spring-summer bighorn ewe lambing ranges of northeastern Utah [prior probabilities P(H) = High = .30; P(L) = Low = .70].

Habitat attributes	Conditional probabilities	
	High	Low
TERRAIN		
1. The area is less than, or equal to, 6400' elevation.	0.67	0.44
2. The average slope of the area is:		
a. less than 35°.	0.11	0.33
b. 35° to 40°.	0.77	0.01
c. greater than 40°.	0.12	0.66
3. More than 75% of the area has aspects between 180° and 270° from north.	0.67	0.11
4. The area is within 100 meters of water source.	0.78	0.33
VEGETATION		
5a. Tree canopy cover is less than, or equal to, 6%.	0.55	0.33
OR		
5b. The area has horizontal visibility greater than, or equal to, 80%.	0.77	0.99
6. The area has shrub cover less than, or equal to, 6%.	0.99	0.43

for these variables before conducting a PATREC analysis. Replacement of PATREC values reported here with more appropriate ones from local situations is not that difficult. For example, in Table 1, habitat attribute 1 indicates that 7250' elevation is a break-point for observed bighorn densities. The assigned probabilities indicate that 78% of the time high densities of rams were observed above 7250', whereas low densities of rams occurred at or above that elevation only 30% of the time. The 7250'-elevation contour corresponds to the canyon rim at Bear Mountain, a steep-sided plateau. Above 7250' bighorn rams utilize the relatively level rim areas, typified by slopes of less than 6° and abundant forage. With little reason to use the steep, less productive cliff areas, rams occur in higher numbers on the rim. Concurrently, driven by behavior to protect their newborn lambs, ewes are found mostly at lower elevations (in cliffs) typified by very steep slopes (35°-40°) (Table 2). Because many transplant sites have similar elevational break-points between precipitous escape terrain and the more level, high-productivity forage areas, managers can

TABLE 3. Habitat evaluation model (PATREC) for fall-winter bighorn ranges of northeastern Utah [prior probabilities  $P(H) = \text{High} = .30$ ;  $P(L) = \text{Low} = .70$ ].

Habitat attributes	Conditional probabilities	
	High	Low
<b>TERRAIN</b>		
1. The area is greater than, or equal to, 7000' elevation.	0.90	0.20
2. The average slope of the area is:		
a. less than 6°.	0.60	0.20
b. 6° to 15°.	0.30	0.01
c. greater than 15°.	0.10	0.79
3. The area is within 275 meters of, but not in, escape terrain.	0.80	0.10
<b>VEGETATION</b>		
4a. Tree canopy cover is less than, or equal to, 5%.	0.90	0.40
OR		
4b. The area has horizontal visibility greater than, or equal to, 90%.	0.90	0.40
OR		
4c. Average shrub height is less than, or equal to, 0.4 meters.	0.90	0.40
5. Grass and forb cover is greater than, or equal to, 14%.	0.70	0.20
6. The area supports greater than, or equal to, 300 kg per hectare (dry weight) of grasses and forbs.	0.80	0.10

reasonably substitute those values. Also, note that each of the three PATREC submodels has several habitat attributes separated by the word "or." Because an underlying assumption of Bayes Theorem is that all habitat attributes are independent, those found to be interdependent are separated by "or," giving the user the option of selecting one of the listed alternatives, allowing for flexibility in the database.

PATREC analysis requires detailed, site-specific information and is tedious to conduct by hand. Manual application (i.e., noncomputer assisted) of PATREC models for wildlife has been successfully conducted for very large areas with satisfying results (Evans 1983, Wilson 1983). However, current GIS computer technology can be successfully employed to perform these same analyses in significantly less time and with much less effort. We fully recommend the GIS approach to PATREC analysis; however, an overview of both approaches is presented here for the

benefit of those with, and without, GIS computer technology.

It is beyond the scope of this paper to discuss the intricacies of PATREC modeling. Therefore, a thorough review of Kling (1980), Evans (1983), or Wilson (1983) is essential, as each of these references contains detailed information regarding the theory, methodology, application, and utility of PATREC models for wildlife. The primary purpose of this section is to present an existing bighorn PATREC model, its application, and utility.

Because the manual and GIS computer approaches to PATREC model application differ widely, each is addressed separately. The following discussion is based on the stepwise procedure outlined in Figure 4. The numbers to the left of each step uniquely identify it and will be referred to below.

#### The Manual PATREC Model Approach

**STEP 1.**—Because PATREC models cannot be applied to an entire bighorn range simultaneously, available bighorn habitat (defined in Part 1) must be subdivided into PATREC model evaluation units (MEU) for the analysis of habitat quality. Once subdivided, each of the analysis subunits is individually evaluated. A subunit of 16.2 ha (40 acres) is suggested, although biologists can adjust the MEU's area as needs dictate. However, as MEU size increases, model resolution will become coarser; and important, high-quality portions of range may go unidentified or be downgraded as they are averaged with adjacent areas of lesser quality. Mylar overlays on topographic maps can provide the necessary analysis grid of MEUs. A data sheet should be constructed that contains a unique label for referencing each MEU and its associated PATREC posterior probabilities.

**STEPS 2 AND 3.**—Each MEU should be evaluated using each of the three submodels (Tables 1–3). If a user suspects that lambing terrain may be inadequate, he may choose to apply only that PATREC submodel while omitting the other two.

Subunit evaluations compare each subunit's habitat attributes with those listed in the PATREC models. If the subunit meets the criteria of each habitat attribute, then the high- and low-conditional probabilities

## PART 2: QUALITATIVE HABITAT ASSESSMENT FLOW DIAGRAM

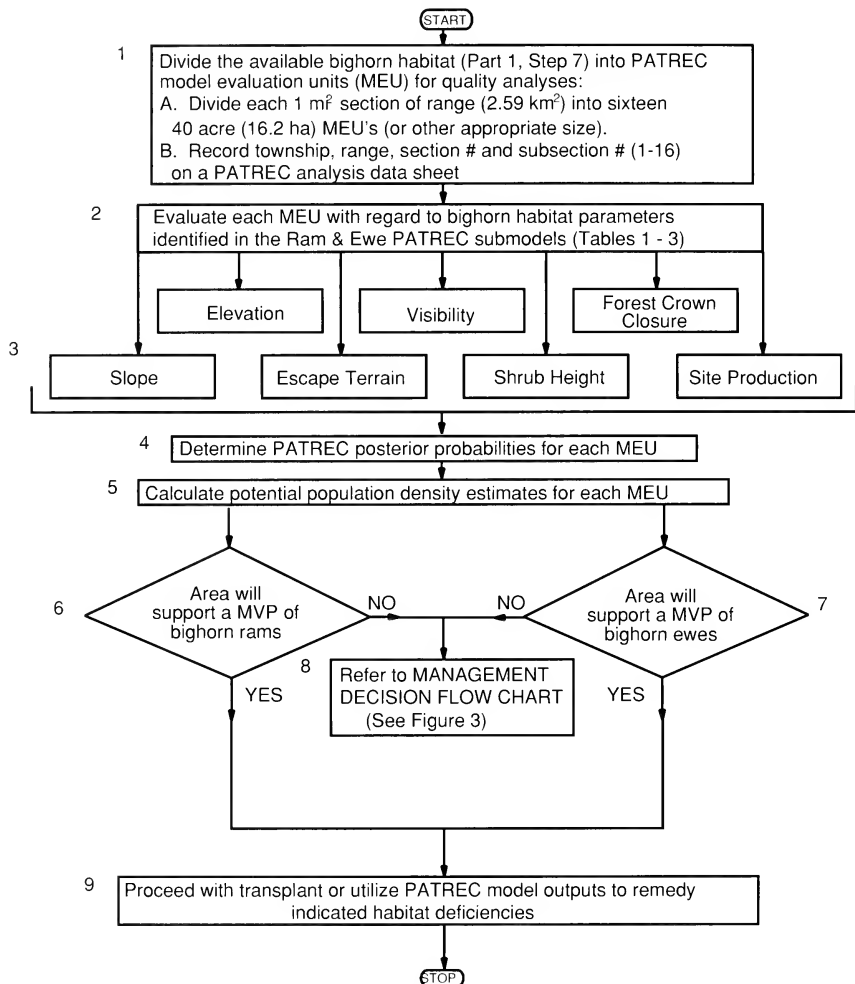


Fig. 4. Part 2: Qualitative Habitat Assessment flow diagram.

associated with each are used in calculation of the site's overall high- and low-density probabilities. When habitat attribute criteria are not met by the site, each high- and low-conditional probability is subtracted from 1 and the result recorded for use in subsequent calculations.

**STEP 4.**—PATREC model outputs are expressed as probabilities. These probabilities express the likelihood that the evaluated parcel of range (MEU) will support a high-density population and the probability it will support a low-density population. Computations to provide these outputs are quite simple and

can be done by hand, though not recommended, or with a hand-held calculator or a computer. Once the required inventory data are gathered from an MEU and compared with habitat attribute criteria, the resulting conditional probabilities  $P(\text{ID}/\text{H})$  and  $P(\text{ID}/\text{L})$  are used in Bayes Theorem as follows:

$$P(\text{H}/\text{ID}) = \frac{P(\text{H}) \times P(\text{ID}/\text{H})}{P(\text{H}) \times P(\text{ID}/\text{H}) + (P(\text{L}) \times P(\text{ID}/\text{L}))}$$

where  $P(\text{H}/\text{ID})$  is the probability that the area will support a high-density population based on inventory data.  $P(\text{H})$  and  $P(\text{L})$  are the probabilities of a high- or low-density area (prior probabilities) naturally occurring. Every subunit has an associated probability of supporting a high density and a low density of bighorn sheep. Since these two probabilities must sum to 1, 1 minus the high-density probability yields the low-density probability. For all three PATREC models the prior probabilities for high and low have been assigned the values of 0.30 and 0.70, respectively. This assignment of values is a reflection of the relative abundance of habitats in northeastern Utah capable of supporting high- and low-density bighorn sheep populations. This implies that a random sample of habitat would select high-density types 3 times out of 10 and low-density types 7 out of 10. These probabilities do not address land beyond the delineated bighorn range boundaries. These values can, and should, be changed to local situations when the proportion of high to low habitat is clearly different. In situations where the proportion is unknown, assigning probabilities of 0.50 to each cancels out the effects of this variable's input on the model (see Kling 1980 for further discussion).  $P(\text{ID}/\text{H})$  and  $P(\text{ID}/\text{L})$  represent the probabilities that the inventory data have a high- or low-density potential, respectively (conditional probabilities). An example here will illustrate how Bayes Theorem is used.

Suppose a particular MEU was evaluated and only habitat attributes 2A, 6, and 7 of the spring-summer bighorn ram model (Table 1) were satisfied. The probability of the site providing high-density habitat for bighorn rams, given those inventory data, is then calculated. It should be noted that when habitat criteria are not satisfied by the site (numbers 1, 3, 4C, and 5), both high- and low-conditional proba-

bilities are subtracted from 1. To illustrate, the necessary calculations are performed:

$$\begin{aligned} P(\text{ID}/\text{H}) &= (\text{product of all seven attributes' high probabilities multiplied}) \\ P(\text{ID}/\text{H}) &= (1-.78)(.67)(1-.89)(1-.67)(1-.67)(.67)(.78) \\ &= 0.000922757 \\ P(\text{ID}/\text{L}) &= (\text{product of all seven attributes' low probabilities multiplied}) \\ P(\text{ID}/\text{L}) &= (1-.30)(.20)(1-.30)(1-.40)(1-.10)(.01)(.33) \\ &= 0.000174636 \end{aligned}$$

These conditional probabilities are then substituted into the Bayes Theorem as follows:

$$\begin{aligned} P(\text{H}/\text{ID}) &= \frac{(0.3)(0.000922757)}{(0.3)(0.000922757) + (0.7)(0.000174636)} \\ &= 0.69 \\ P(\text{L}/\text{ID}) &= 1.0 - 0.69 = 0.31 \end{aligned}$$

From these inventory data, we can conclude that the probability of the area supporting a high density of bighorn sheep is 0.69, or 69%. Conversely, the probability that the same area would support a low-density population is 0.31 or 31%.

STEP 5.—As discussed in step 8 of Part 1, bighorn population densities ranging from less than 0.4 bighorn per  $\text{km}^2$  (1 per  $\text{mi}^2$ ) (McQuivey 1978) to over 27 per  $\text{km}^2$  (70 per  $\text{mi}^2$ ) (Demarchi 1965) have been reported. For the sake of this model it is assumed that low-density habitat will support 1.0 bighorn per  $\text{km}^2$  and high-density habitat will support 25 bighorn per  $\text{km}^2$ . Based on those density estimates, PATREC predicts that the MEU will support (0.69)(25 bighorn/ $\text{km}^2$ ), or 17 bighorns per  $\text{km}^2$ , when the population is at, or near, its carrying capacity.

STEPS 6 AND 7.—Because PATREC outputs can be translated into the long-term population densities that a range can be expected to support (discussed in step 5), the number of rams and ewes that an area may be expected to support can be calculated. Although the percent composition of rams, ewes, yearlings, and lambs varies from herd to herd, it is recommended that ram habitat be able to support at least 25 adult rams (four years old and older), and the ewe habitat at least 100 members of the ewe super-class (all ewes, yearlings, and lambs).

STEP 8.—If the PATREC model reveals deficiencies, management may choose to focus on each deficiency individually. The Management Decision Flow Diagram guides decision making in those instances.

STEP 9.—PATREC models also provide some insight as to what management could do to improve the area for bighorn sheep. In the above example, there is little that can be done about habitat attributes 1 (elevation) or 3 (amount of escape terrain), but 4C and 5 (shrub height and herbaceous vegetation cover) could be managed so that the probability of the area supporting a larger population could be increased. By trying various "What if?" scenarios, managers can also identify alternative habitat modifications most likely to have high cost/benefit returns. For instance, if managers were to alter shrub height by burning and thereby satisfy attribute 4C, the resultant  $P(H/ID)$  is 0.87, for a net increase in habitat suitability of 18%. However, if managers had chosen to alter attribute 5 instead by increasing the total herbaceous plant cover, the resulting probability that the site will be capable of supporting a high-density population would have increased to 0.98, giving a net increase of 29%. Once the differential in cost is calculated for each scenario, the plan of action that will return the most per unit effort invested will be apparent.

#### The GIS Computer PATREC Model Approach

No flow diagram has been provided for the GIS computer PATREC model approach. However, the following discussion should assist the reader in understanding an overview of the process.

As with the manual method, the entire bighorn range must be analyzed with each of the PATREC submodels for accurate habitat assessment. The GIS approach circumvents the need for subdividing the evaluation site into analysis units and thereby avoids the tedium associated with it. Instead, the habitat requirements specified by each submodel are used to identify qualifying portions of the GIS data base. For example, the ram spring-summer PATREC submodel (Table 1) indicates in habitat attribute 1 that elevations above and below 7250' are important in determining habitat suitability. For this elevational

attribute, the user would access the digital elevation map and reclassify it into only two categories: those above 7250' and those below 7250' elevation. Secondly, all areas (polygons) within each category would be encoded with the appropriate conditional probabilities, as presented in Table 1. Because areas below 7250' elevation do not meet the given habitat criteria, they are labeled with 1 minus the given probabilities. In a like manner, the user proceeds to subdivide the GIS data base according to each of the habitat criteria listed, labeling each newly created category of polygons with the appropriate conditional probability values. Finally, all polygons are merged to create a composite map comprised of the intersection of all habitat attributes and associated probabilities. The GIS creates a new table for each polygon containing an entire listing of the conditional probabilities associated with its particular habitat attributes, as specified by the PATREC submodels. A composite map of these merged polygons is created independently for each submodel.

The information stored in the relational data base for each range polygon is used to calculate resultant probabilities using Bayes Theorem, as demonstrated above. Fortunately, many GIS applications have the ability to access the stored values, perform these time-consuming calculations for each subunit, and return the results, i.e., probabilities, for each polygon. The GIS can then use these resultant probabilities to calculate estimates of bighorn densities for each polygon. As in the manual method, the total number of sheep the site is capable of supporting is determined by summing the estimated density values for all polygons. These individual values (i.e., number of rams in spring-summer, number of ewes during lambing, etc.) must exceed those presented above in step 6 of the Manual PATREC approach. In this manner, seasonal/cohort weaknesses of a site are identified, and management can focus on the real problem areas. GIS utility and power streamline the PATREC process immensely and put within reach of many this powerful tool for habitat quality evaluation.

This concludes application of Part 2 of the bighorn HEP. Upon completion of bighorn habitat evaluation, the investigator should know whether or not an evaluated site could support reintroduced bighorn sheep and what

could be done in the event limiting factors need attention.

### CONCLUSIONS

Although efforts have been underway for several decades to reestablish Rocky Mountain bighorn sheep to formerly occupied ranges, many transplant efforts have failed. In order for Utah, and other western states, to have a more successful reintroduction program, a rigorous, biologically based habitat assessment procedure has been devised. It is hoped that this procedure will help managers avoid "doomed-from-the-start" reintroductions and greatly enhance transplant success.

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## OBSERVATIONS ON THE DEVELOPMENTAL BIOLOGY OF *CICINDELA ARENICOLA* RUMPP (COLEOPTERA: CICINDELIDAE)

Karen Lyn Bauer<sup>1</sup>

**ABSTRACT.**—*Cicindela arenicola* Rumpff is being considered for threatened and endangered status by the U.S. Fish and Wildlife Service. Little is known about the developmental biology of this species.

Adults of *C. arenicola* were active from April through late June and late August through early November, but generally they were not on the surface when temperatures were below 19°C or above 45°C, or when conditions were windy, cloudy, or rainy. Mating and egg-laying occurred only during the spring.

Five size classes (1-, 2-, 3-, 4-, and 5-mm diameters) of larval burrow openings were observed. Burrows of 5 mm had a mean depth of  $42.23 \pm 8.81$  cm (1 S.D.). Larvae of *C. arenicola* were active from April through June and late September through mid-November.

Developmental times and larval size were affected by food supplementation. Nearly all food-supplemented, 1-mm, first instars molted to larger second instars of 3-mm diameter. Most nonsupplemented larvae spent several months as 2-mm second instars before growing to 3 mm in diameter. Food-supplemented larvae reached the third instar in approximately 13 months, while nonsupplemented larvae took slightly over two years to reach this stage. Development from egg to adult was estimated at two years for food-supplemented larvae and three and one-half to four years for nonsupplemented larvae.

Cattle had a significant effect on larval mortality. A high percentage (76–80%) of larval *C. arenicola* that were stepped on by cattle never reopened their burrows. Only 14% of undisturbed larvae never reopened their burrows. Approximately 15% of 150 larvae marked in 1988 reopened burrows in 1989.

**Key words:** tiger beetle, life cycle, food supplementation, mortality factors.

Eighty-five species of tiger beetles of the genus *Cicindela* exist in the United States (Boyd 1982). The adults of these species are more readily studied than are the larvae; thus, the majority of larvae are poorly known biologically.

One to several years are required for cicindelids to develop from egg through three larval instars to adult. Partial or complete life cycles have been worked out for only a few of the world's nearly 2000 described Cicindelidae (Willis 1967, Arnett 1963).

Most adult tiger beetles are diurnal predators that visually search for small arthropods and other prey on the surface in open, sparsely vegetated habitats. Sedentary tiger beetle larvae, which construct vertical burrows in the substrate, position themselves at the burrow entrance and wait for prey to pass within striking distance.

*Cicindela arenicola* Rumpff (1967), a sand-dwelling species, is being considered by the U.S. Fish and Wildlife Service for rare and

endangered status. Little is known about its developmental biology. This species has been found in Idaho on the St. Anthony Sand Dunes, the Bruneau Sand Dunes, a series of sand dunes in Power County, and a few other small dunes along the Snake River Plain. The St. Anthony Sand Dune adult population is the largest (fewer than one million individuals), and the population in Power County is the second largest in the state (Anderson 1989). *C. arenicola* is the only species inhabiting the dunes in Power County.

Tiger beetle populations can be influenced by such weather conditions as temperature, moisture, wind, and cloud cover (Shelford 1908, Willis 1967, Knisley 1987, Mury Meyer 1987, Pearson and Lederhouse 1987). Availability of food is a major factor limiting tiger beetle development (Shelford 1908, Willis 1967, Palmer 1978, Palmer and Gorrick 1979, Knisley and Pearson 1984, Pearson and Knisley 1985, Knisley and Juliano 1988).

The objectives of this study were to: (1)

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determine when the adults and larvae are active, (2) describe the developmental biology of larvae and the length of the life cycle under a supplemental food regimen and under natural conditions (no food supplementation), and (3) determine hazards and mortality factors for the populations.

#### MATERIALS AND METHODS

This study was conducted from May to November 1988 and April to September 1989 in the Wapi area approximately 17 miles west of American Falls, Power County, Idaho. The study site (approximately 150 m  $\times$  50 m) consists of a series of wet sand dunes surrounded by sagebrush. The sand is fine and buff colored.

This region of Idaho is classified as a cold desert with yearly precipitation averaging 10.42 inches. Droughts occurred in 1988 and 1989. Total precipitation during April through October for 1988 and 1989 was 2.53 inches and 4.34 inches, respectively, and was 40–70% of the average expected precipitation for these months (Climatological Data for Idaho 1988–1989). Average maximum ambient daytime temperatures ranged from 10–15 C in April to 30–38 C in July and August. Temperatures on the surface of the dunes at mid-day ranged from 19 to 60 C during the study period.

Vegetation on the dunes was sparse, prominent species being *Elymus flavescens* Scribn. and Smith (yellow wild rye), *Chrysothamnus viscidiflorus* (Hook.) Nutt. (gray rabbitbrush), *Chrysothamnus nauscosus* (Pall.) Britt. (green rabbitbrush), *Rumex crispus* Pursh (wild begonia), *Abronia multiflora* Dougl. (white sand verbenia), *Oenothera pallida* Lindl. (pale evening primrose), and *Psoralea lanceolata* Pursh (lance-leaf scurf-pea). Monthly visual estimates of percentage of cover on portions of the dunes supporting larval and adult beetles were April, 4–6%; May, 7–9%; June, 15–17%; July, 15–20%; August, 11–15%; September, 9–15%; and October, 6–10%.

On 23 May 1988, 100 burrows of larval *C. arenicola* were marked by placing two surveyor's flags 8 in. apart with the larval burrow centered between them. A labeled wooden nursery tag was placed 2 in. from the burrow between the flags. Some burrows were located within a few centimeters of yellow wild rye culms, but usually they were not

as close to other vegetation. Most larval burrows were located on the flattened, bowl-shaped portions of the dunes. Burrows of all diameters (1, 2, 3, 4, and 5 mm) were monitored throughout the study. The larvae in these burrows were not given supplemental food. Clear plastic, 14-ounce cups were placed over 33 larger burrows (4- and 5-mm diameter) in mid-August 1988 to capture any adult beetles as they emerged.

On 4 June 1988, 50 larval burrows, 1 mm in diameter, were marked in the same manner described above. These larvae were given supplemental food, provided as first or second instar larvae of *Tenebrio molitor* L. on the day of initial marking and every time their burrows were open (but never more often than twice each week). The *Tenebrio* larvae provided in this manner represented minimum dietary intake, as the *C. arenicola* larvae may have acquired additional prey on their own during the study period.

Twice each week during the two seasons (beginning in May 1988 and April 1989) the burrow diameters of the food-supplemented and nonsupplemented groups were measured using a draftsman's circle template. Visits to the sand dunes were made at 7- to 10-day intervals during the hot, dry periods from July through mid-August 1988.

In the 1989 season (April through July), diameters of unmarked larval burrows were measured approximately twice each week during a 30-minute traversing of the study site. Surface temperature, cloud cover, presence or absence of wind, and rainfall, if any, were noted. A visual census of the number of adult beetles present on the surface of the study site was taken.

Twelve 5-mm-diameter larval burrows were randomly chosen for depth measurements. Thin plaster was poured down each burrow and allowed to harden. The next day these burrows were excavated carefully and measured for depth.

The Bureau of Land Management has jurisdiction over the open rangeland where this study was conducted. Grazing is allowed, and it is not uncommon for cattle to roam the dunes in search of food when the available resources in the sagebrush areas dwindle. This usually occurs before the end of May. If a marked larval burrow was disturbed by cattle, it was noted.

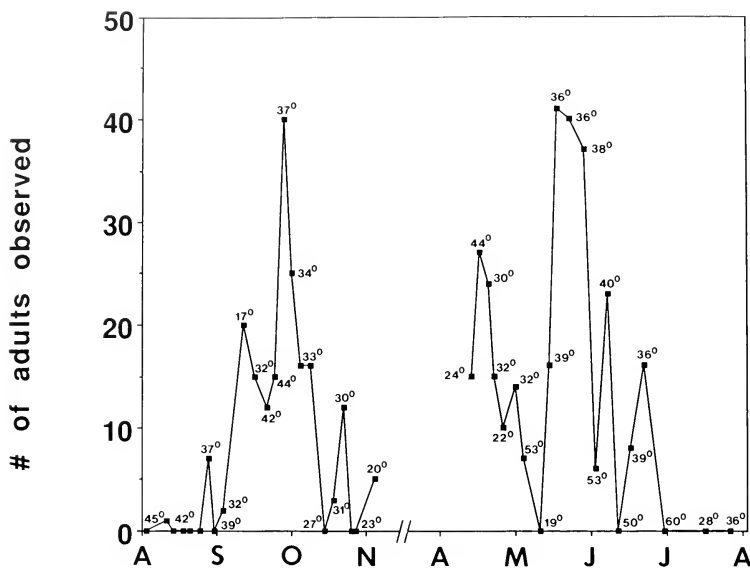


Fig. 1. Number of adult *C. arenicola* observed on study site, 2 August–5 November 1988 and 15 April–30 July 1989. Values were obtained by traversing the study site for 30 minutes twice weekly. Surface temperatures (°C) were taken at midday.

## RESULTS

**ADULT ACTIVITY.**—Adult *C. arenicola* were active in the spring and fall on sunny, warm (19–45 C) days and also after a rain shower when the surface was moist. They burrowed beneath the sand during windy, cloudy, or cool (surface temperature below 19 C) conditions, or any combination of these. Adults were also inactive when surface temperature was above 45 C, unless clouds reduced radiant heat from the sun (Fig. 1).

Adult beetles generally appeared on the surface during the first or second week of April when they fed, mated, and laid eggs on warm, sunny days after the snow had melted. Few, if any, adults remained by the first week of July, and usually none were seen in July and August (Fig. 1). Beginning in late August or early September, fall adults emerged, with peak emergence near the end of September. Adults fed but were not observed to mate during the fall. Numbers of adults on the surface gradually diminished through October, and none were present by early November

(Fig. 1). They had burrowed beneath the sand where they hibernated.

**LARVAL ACTIVITY.**—Five size classes (diameters) of larval burrows were observed: 1, 2, 3, 4, and 5 mm. The 5-mm burrows had a mean depth of  $42.23 \pm 8.81$  cm (1 S.D.). The number of active larval burrows increased during April, peaked in May, and then declined through June for all size classes except the 2-mm size class, which showed its highest numbers during June (Fig. 2). Burrows were rarely open from July through mid-September. During late September through October some burrows were open, but fewer than in the spring.

A chi-square test of association (Zar 1984) was performed on the data for unmarked larval burrows, which were censused randomly in 1989. The data for 15 April, 13 May, and 14 June were used. The null hypothesis (i.e., the number of each size diameter of open larval burrows of *C. arenicola* is independent of the month in which they are measured) was rejected. A  $\chi^2$  value of 146.1 was calculated

TABLE 1. Results of food supplementation of fifty 1-mm *C. arenicola* larvae monitored during June–November 1988.

Larval growth	Number of times fed					
	1	2	3	1	5	9
No change	2 (8%)	13 (87%)	4 (67%)	0	0	0
Increased one size class	0	0	0	1 (50%)	0	0
Increased two size classes	2 (8%)	2 (13%)	2 (33%)	1 (50%)	1 (100%)	1 (100%)
Never reopened	21 (84%)	0	0	0	0	0
TOTAL	25	15	6	2	1	1

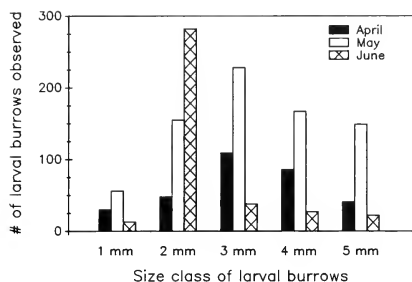


Fig. 2. Relative numbers of larval burrows of *C. arenicola* for five size classes existing at the study site, April–June 1989. Values were obtained by traversing the study site for 30 minutes twice weekly.

and compared to a table value of 15.507 at  $\alpha = .05$  and 8°f.

**OUTCOMES OF LARVAE.**—Table 1 summarizes the results of food-supplemented larvae of *C. arenicola* during 1988. Each larva was categorized according to the number of times it accepted supplemental food and the amount of growth (increase in size class) observed. Eighty-four percent of 1-mm-diameter larvae that had one food supplement never reopened their burrows in 1988 (Table 1). Some larvae that had one to three food supplements showed no change in size class, but all larvae that received four or more food supplements increased one or two size classes (Table 1). Only three of the food-supplemented larvae showed activity in 1989. Of these three, two that received one or two supplemental feedings showed no increase in size, and one larva that received three supplemental feedings increased from the 3-mm to the 4-mm size class.

Tables 2 and 3 summarize the results of nonsupplemented larvae of *C. arenicola*. Each larva was categorized according to its size class and the amount of growth (increase in size class) observed. Larvae of 1-mm diameter showed no change or did not reopen their

burrows after initial marking (Table 2). No 1-mm larvae reappeared in 1989 (Table 3). During 1988, 23 of 100 nonsupplemented larvae never reopened their burrows, 33 showed no change in size class, 26 increased one size class, 7 increased two size classes, and 1 emerged as an adult. Also during 1988, 4 nonsupplemented larvae increased three to five size classes, and 6 showed a decrease in size class (Table 2). Occasionally, a few larval burrows had irregularly shaped entrances measuring 6–7 mm. Some returned to their former size in a few days. During 1989, 18 of the 100 nonsupplemented larvae marked in 1988 were active (burrows open); 2 of these larvae opened their burrows one time only, 7 showed no change in size class, 8 increased one size class, and 1 increased two size classes (Table 3).

**PROPOSED LIFE CYCLES.**—Life cycles of *C. arenicola* were constructed for the food-supplemented and nonsupplemented larvae (Fig. 3). The proposed life cycle of two years for food-supplemented larvae approximates the minimum time required for development, while the life cycle of three and one-half to four years for nonsupplemented larvae approximates the maximum time required for development from egg to adult.

**CATTLE ACTIVITY.**—Contingency tables (Tables 4 and 5) were prepared regarding the disturbance by cattle of burrows belonging to food-supplemented and nonsupplemented larvae of *C. arenicola* and the reopening of the larval burrows after disturbance. Chi-square tests of association employing Yate's correction (Zar 1984) were performed to test the null hypotheses (i.e., there is no significant association between the reopening of burrows belonging to food-supplemented [or nonsupplemented] larvae of *C. arenicola* and whether or not the burrows had been disturbed by cattle previously). The null hypotheses were rejected in both cases, indicating that disturbance by cattle had a significant effect on the

TABLE 2. Results of each size class of 100 nonsupplemented larvae of *C. arenicola* monitored during May–November 1988.

Larval growth	Size class of larval burrows				
	1 mm	2 mm	3 mm	4 mm	5 mm
No change	1 (33%)	8 (23%)	4 (14%)	20 (63%)	0
Increased one size class	0	11 (31%)	10 (34%)	5 (16%)	0
Increased two size classes	0	5 (14%)	1 (3.5%)	1 (3%)	0
Increased three to five size classes	0	3 (9%)	1 (3.5%)	0	0
Never reopened	2 (67%)	8 (23%)	9 (31%)	3 (9%)	1 (100%)
Decreased in size class	0	0	4 (14%)	2 (6%)	0
Adult emerged	0	0	0	1 (3%)	0
TOTAL	3	35	29	32	1

TABLE 3. Results of surviving, nonsupplemented larvae of *C. arenicola* from 1988 monitored during April–September 1989.

Larval growth	Size class of larval burrows			
	2 mm	3 mm	4 mm	5 mm
No change	0	1 (50%)	5 (38%)	1 (50%)
Increased one size class	0	0	8 (62%)	0
Increased two size classes	1 (100%)	0	0	0
Never reopened	0	1 (50%)	0	1 (50%)
TOTAL	1	2	13	2

TABLE 4. Summary of the reappearance of burrows of food-supplemented larvae of *C. arenicola* related to cattle disturbance.<sup>a</sup>

	Supplemented larvae (1 mm)		
	Disturbed	Undisturbed	Totals
Never reopened	22	3	25
Reopened	7	18	25
TOTALS	29	21	50

<sup>a</sup> $\chi^2$  18.56,  $\alpha$  .05, 1 d.f.

reopening of larval burrows. Seventy-six percent of food-supplemented larvae and 80% of nonsupplemented larvae disturbed by cattle never reopened their burrows. Fourteen percent of larvae that were undisturbed by cattle never reopened their burrows independent of whether larvae were food-supplemented or nonsupplemented (Tables 4 and 5).

It should be noted that two of the seven food-supplemented larvae that reopened their burrows after being disturbed did not reopen their burrows after one more disturbance by cattle.

TABLE 5. Summary of the reappearance of burrows of nonsupplemented larvae of *C. arenicola* related to cattle disturbance.<sup>a</sup>

	Nonsupplemented larvae (all size classes)		
	Disturbed	Undisturbed	Totals
Never reopened	35	8	43
Reopened	9	48	57
TOTALS	44	56	100

<sup>a</sup> $\chi^2$  42.81,  $\alpha$  .05, 1 d.f.

## DISCUSSION AND CONCLUSIONS

ADULT ACTIVITY.—*Cicindela arenicola* follows seasonality patterns similar to those described for *C. repanda* Dej., *C. formosa* Say, and *C. scutellaris* Say (Knisley 1979). Typically, adults that emerged during the previous fall and spent the winter hibernating appear on the surface in April and are joined in the next several weeks by spring adults, which emerge for the first time. The spring and fall adults mature sexually, mate, and lay eggs that hatch in two to three weeks. Most of the adults die by early July. Pupae that develop during late summer produce the fall adults, and these emerge in late August and are active during September and October until they dig burrows for hibernation (Fig. 1).

The early spring peak in adults for April 1989 (Fig. 1) may represent fall adults from 1988 that had emerged from hibernation. The second peak in late May probably indicates the time of emergence of spring adults from overwintered pupae. However, Shelford (1908) reports that populations of older individuals of *C. hirticollis* Say gradually died off as the new individuals emerged, so that the

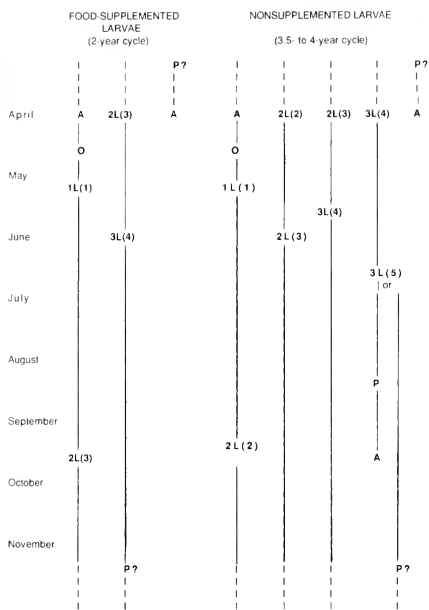


Fig. 3. Proposed life cycles for food-supplemented and nonsupplemented larvae of *C. arenicola*. (A = adult, O = oviposition, 1L = first instar, 2L = second instar, 3L = third instar, P = pupa, ---- = hibernation, — = active larvae.) Numbers in parentheses after instars indicate diameters (mm) of larval burrows.

presence of the younger beetles cannot be detected by population increase. This suggests that the major peak observed in May 1989 represents a majority of spring adults and fewer fall adults, many of which had mated, laid eggs, and begun to die.

The data in Figure 1 show that the majority of fall adult *C. arenicola* emerged during September. Minor peaks and sharp declines in the numbers of adult tiger beetles were probably the result of adverse weather conditions. Tiger beetles dug temporary burrows in response to very cool or very hot surface temperatures, or cloudy, rainy, or windy conditions. Willis (1967) and Pearson and Lederhouse (1987) reported similar effects of weather upon *Cicindela* species. Pearson and Lederhouse (1987), who studied the thermal ecology of 13 species of southwestern U.S. adult tiger beetles, reported a lethal ( $LT_{50}$ ) maximum thoracic temperature of 47.2–

48.9°C, a minimum thoracic temperature of 14.4–21.2°C, and optimum foraging temperatures of 30.2–37.2°C. Observations of surface activity recorded for adult *C. arenicola* corresponded with their results, considering that *C. arenicola* may be active at cooler surface temperatures on sunny days and at higher surface temperatures on partly cloudy days.

*Cicindela arenicola* was never observed to mate during the fall. Shelford (1908) reported that no female *C. hirticollis* contained eggs in the fall and that they were never seen copulating. Furthermore, hibernating species do not reach sexual maturity in autumn. Theoretically, larvae hatched from eggs laid in the fall would not be able to obtain enough food to store energy necessary to survive winter conditions. Adult tiger beetles typically reach sexual maturity in the spring and copulate on warm, sunny days.

**LARVAL ACTIVITY: SIZE CLASSES.**—All tiger beetles of the genus *Cicindela* that have been studied exhibit three instars, the same being presumed for *C. arenicola* (Rumpp 1967). Burrow diameter is an indication of instar because the diameter is nearly the same size as the prothorax and head width of the larva (Willis 1967, Knisley and Pearson 1984, Knisley 1987). Exact instar can be distinguished if the species is known.

Tiger beetle larvae enlarge their burrows with each molt. Shelford (1908) reported that newly molted second instar larvae of *Cicindela* possessed abdomens similar in size to late first instar larvae. Newly molted larvae have wrinkled abdominal cuticula; thus, room for growth is allowed. Palmer (1978) proposed that larvae may not molt until a certain threshold body weight is reached. Although the results were inconclusive, Palmer and Gorrick (1979) suggested that some larvae may molt at higher body weights and others at lower body weights in relation to the abundance and/or regularity of food. Molting is indicated by an increase in burrow diameter preceded by a period of plugging (Willis 1967, Knisley 1987).

Five distinct diameters of larval burrows were observed for *C. arenicola*, but this pattern probably indicates size variation within the three larval instars, not five instars for this species. Usually, periods of plugging were not observed between the 2-mm and 3-mm size classes or the 4-mm and 5-mm size classes of

larval burrows. Plugging, followed by increases in burrow diameter, was observed between the 1-mm and 2–3-mm size classes, and the 3-mm and 4–5-mm size classes, indicating that molting probably occurred between these stages. Width of prothorax, by instar, for 12 species of *Cicindela* was reported by Shelford (1908). Collectively, the 12 species had pronotal width ranges of 0.7–1.75 mm ( $\bar{x} \approx 1.21$  mm) for first instar larvae, 1.3–3 mm ( $\bar{x} \approx 1.90$  mm) for second instars, and 1.8–5 mm ( $\bar{x} \approx 3.18$  mm) for third instars. Excluding the 1.8-mm width for third instars, the pronotal widths were generally 3.5–4.5 mm for most species at the third instar stage. It can be concluded that the 1-mm size class corresponds to the first instar, the 2-mm and 3-mm size classes to second instars, and the 4-mm and 5-mm size classes to third instars for larval *C. arenicola*.

**BURROW DEPTH.**—Burrow depth is related to a variety of factors such as type of soil, temperature, proximity to ground water, species, and instar (Shelford 1908, Willis 1967, Knisley 1987). Larvae of sand-dwelling species usually have deeper burrows than species living in other habitats (Shelford 1908, Knisley 1987). Rumpp (1967) reported burrow depths of 15 cm for full-grown larvae of *C. arenicola*. In this study, 5-mm third instar larvae of *C. arenicola* were shown to have a burrow depth of  $42.23 \pm 8.81$  cm. This compares favorably with the burrow depths of 15–20 cm, 30–50 cm, and 60–90 cm reported by Shelford (1908) for other sand-dwelling species. Sand becomes very dry several inches below the surface during the summer and especially during droughts. Deeper burrows allow larvae to escape desiccation and retreat to moister areas and cooler temperatures (Knisley 1987). Larvae dig deeper burrows with each successive molt. At this study site sand temperatures 30 cm or more below the surface were fairly constant (24–27 C).

**NUMBERS OF LARVAL BURROWS.**—Many tiger beetle larvae exhibit unimodal or bimodal (spring-fall) activity and are usually active earlier and later in the season than are the adults (Willis 1967, Knisley 1987, Mury Meyer 1987). Larval *C. arenicola* showed bimodal activity. The larval burrows appeared early in April, probably in response to warmer temperatures and surface moisture. Numbers

of larval burrows increased through May, then declined during June as temperatures became much warmer, the sand dried out near the surface, and food became scarce. No larval burrows were observed in July because the larvae plugged their burrows during the hot, dry conditions. Burrow plugging has been correlated with periods of drought (Shelford 1908, Willis 1967, Knisley and Pearson 1984, Knisley 1987). Cicindelid larvae of spring-fall species may estivate during the hottest months of summer (Shelford 1908) and then reopen in the autumn when they resume feeding.

Unlike the other size classes, the 2-mm size class showed its highest numbers in June rather than May (Fig. 2). Some of these larvae may have overwintered from the previous year while others may have molted recently from the 1-mm to the 2-mm size class. Therefore, at least two generations of *C. arenicola* may be represented here.

The number of each size class of open larval burrows of *C. arenicola* is dependent upon the month in which the burrows were censused and measured, as was suggested by a chi-square test of association. Moisture (snow-melt) would be ample in April, and when combined with mild temperatures, some larvae would appear at the tops of their burrows. In May the amount of moisture might be slightly less, but with warmer temperatures, many more larvae would surface. By the end of June moisture near the soil surface is diminishing considerably and the temperatures become hot, resulting in most larvae closing their burrows, then retreating to the bottom where they spend the summer months.

**OUTCOMES OF LARVAE.**—Availability of food may be the limiting factor controlling tiger beetle development (Knisley and Juliano 1988). Lack of sufficient food has been reported to increase the developmental time of larval instars (Shelford 1908, Willis 1967, Knisley and Pearson 1984, Pearson and Knisley 1985, Knisley and Juliano 1988). Supplemental food decreases developmental time (Palmer 1978, Palmer and Gorrick, 1979, Knisley and Pearson 1984, Pearson and Knisley 1985, Knisley and Juliano 1988). In a comparison of food-supplemented and nonsupplemented larvae of *C. arenicola*, supplemental food decreased the time required for development, especially from first to second instar.



The high mortality shown by a majority of food-supplemented larvae that received only one feeding may have resulted from lack of sufficient food and/or desiccation, as first instar burrows are not usually very deep. If subjected to high temperatures, small larvae are unable to retreat into their burrows to much cooler depths as large instars can.

Most larvae that were fed two or three times did not show an increase in size class, suggesting that they must have obtained enough food to survive but not to store the energy to molt. Larvae fed four or more times increased one, and usually two, size classes, implying that they probably had obtained sufficient food to grow and molt to a larger size.

Willis (1967) reported that only one meal of sufficient size is required for first instar larvae to molt, and that second and third instars need several meals to accomplish the same. Evidently, for most surviving 1-mm larvae of *C. arenicola*, one small *Tenebrio* larva was not sufficient to allow molting to occur. However, if tiger beetle larvae obtained several *Tenebrio* larvae (in addition to food they captured independently), nearly all were able to skip the 2-mm size class and molt to become 3-mm larvae.

Most nonsupplemented larvae generally passed through all five size classes and did not skip sizes as their better-fed counterparts did. Mortality was substantial for first instars and somewhat less substantial for the 2- and 3-mm size classes. Desiccation may have accounted for some of the mortality seen for first instars, but lack of food was probably the major cause for most of the mortality incurred by the 1-, 2-, and 3-mm size classes.

Many larvae did not change size classes from April through October, indicating that the larvae were probably not capturing enough food to grow or molt. This trend was seen for many 4-mm larvae. The length of time spent as a third instar larva can range from several months to a few years (Shelford 1908, Willis 1967); therefore, it may not have been unusual for 4-mm (third instar) larvae of *C. arenicola* to remain the same size throughout an entire year.

Nonsupplemented larvae that increased in size usually graduated one size class. Fewer larvae increased two size classes at a time. Most of these larvae probably captured suffi-

cient food to grow and molt, while a few of them captured enough food to skip a size class and molt at a larger size.

Occasionally, larvae showed increases of three to five size classes. This could have been the result of erosion of the burrow entrance or predators in search of food. Peculiar digging, perhaps that of small rodents, was observed where larval *C. arenicola* were located. Those larval burrows showing decreases in size could have been partially plugged when they were measured, or the original larvae might have died and new larvae hatched from eggs laid there coincidentally.

Some 4-mm larvae emerged as adults and were captured under plastic cups placed over their closed burrows in late August. Many of the 4-mm larvae that never reopened their burrows may have emerged as adults but were not caught. Most tiger beetles dig side chambers where they pupate, and the adults do not necessarily emerge along the old larval burrow (Willis 1967). The diameter of plastic cups placed over the larger burrows may not have been sufficient to capture all emerging adults.

**PROPOSED LIFE CYCLES.**—Rumpp (1967) predicted that the life cycle of *C. arenicola* might be similar to the two-year cycle developed by Shelford (1908) for *C. hirticollis*, a sand-dwelling species with a similar seasonality pattern. Knisley (1987) reported a two- to three-year life cycle for a population of *Cicindela marutha* Dow existing on one sand ridge and a three- to four-year life cycle for this same species on another sand ridge. His observations suggest that variability in the length of the life cycle is possible within a species.

Two years appears to be near the minimum developmental time required for food-supplemented *C. arenicola*. Food-supplemented larvae probably could not have been supplemented with food much more often than they were during the experimental period because the larvae plugged their burrows during hot, dry conditions. Nonsupplemented *C. arenicola* may take three and one-half to four years to develop from egg to adult, depending upon the abundance of food on the sand dunes. Under natural conditions, a life cycle of at least three years probably would be observed because food tends to be scarce in sand dune habitats.

The life cycle of *C. arenicola* may be variable and overlapping for several generations (i.e., second instar larvae may have reached this stage in any one of three years, making it impossible to tell which year the egg was laid that developed into a particular 2-mm or 3-mm larva). Abundance curves have been used as an indicator of the length of the life cycle for other cicindelid species (Knisley et al. 1987). Caution must be exercised in situations involving overlapping generations to reduce the possibility that more than one generation unknowingly is being monitored simultaneously. One way to do this would be to mark and monitor only first instar larvae through their full development.

**CATTLE ACTIVITY.**—Willis (1967) reported that cicindelids are usually absent from areas where frequent or prolonged disturbance by man or cattle occurs, although larvae are able to tolerate some amount of disturbance such as cattle walking.

Knisley et al. (1987) attributed increased vehicular traffic as a cause of a dramatic decline in populations of *C. d. dorsalis* subjected to such disturbances. Beetles were present where human activity was low and vehicles were restricted, but no beetles were present where off-road-vehicle traffic was heavy.

When cattle disturbed (stepped upon) larval burrows of *C. arenicola* once, most of the burrows never reopened. Size class and feeding status made no difference. Further disturbance caused most larvae to disappear. In contrast, significantly fewer larvae that were never disturbed by cattle never reopened their burrows. Again, size class and feeding status made no difference.

Because *C. arenicola* has a relatively long life cycle, the chance of disturbance is high in the presence of cattle. Many larvae, limited by availability of food, spend time at the tops of their burrows in order to catch prey. If disturbed at this time, the larvae are most certainly in danger of being crushed, especially because cattle sink several inches into the sand when they walk on it. Cattle were present on the dunes from the third week of May through the middle or end of September, when the BLM required them to be removed. The feeding periods of larval *C. arenicola* coincided with cattle activity on the dunes.

Suitable habitat may be reduced by frequent disturbance, and when natural mortal-

ity factors are considered, populations could be reduced to the point of extinction (Knisley et al. 1987). However, because *C. arenicola* lives in ever-changing sand dune habitats, disturbance of the surface may be important in preventing overgrowth of plants or invasion by others. Ironically, cattle impact, which appears to be so damaging to individual larval *C. arenicola*, may be providing suitable habitat for these beetles as a species.

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## TREE SIZE AND UNDERSTORY PHYTOMASS PRODUCTION IN A WESTERN JUNIPER WOODLAND

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**ABSTRACT.**—Understory phytomass production in a western juniper (*Juniperus occidentalis*) woodland was examined relative to tree size in central Oregon in 1983 and 1984. Vegetation was sampled in two zones, the canopy zone (beneath the canopy) and the intercanopy zone (the space between canopies), on two adjacent sites—a lower slope site with shallow soil and an upper slope site with deeper soil. Sampling was stratified into three tree size classes. Individual species production was significantly affected by tree size and location relative to tree canopy. Production of bottlebrush squirreltail, bluebunch wheatgrass, cheatgrass, miscellaneous annual grasses, perennial forbs, and annual forbs increased with increasing tree size. Sandberg bluegrass production was greater in the intercanopy than the canopy zone, while production of bottlebrush squirreltail, bluebunch wheatgrass, miscellaneous annual grasses, and both perennial and annual forbs was greater in the canopy zone. Production of cheatgrass was determined by the interaction of tree size and zone. Phytomass relationships were expressed to a greater degree on the upper slope site, where total production exceeded that of the lower slope site by approximately 50% the second year of the study.

Individual trees appear to exert a great influence on associated vegetation as western juniper woodlands progress from the seedling (tree establishment) phase to closed stands of mature trees. Original community dominants appear to be spatially segregated beneath tree canopies and associated with large trees, while formerly less common species, such as cheatgrass, come to dominate the entire site.

**Key words:** *Juniperus occidentalis*, western juniper, phytomass production, understory, tree size.

Western juniper (*Juniperus occidentalis* Hook., subsp. *occidentalis*) was historically associated with desert-grassland vegetation and primarily occurred in open stands, on plateaus, or on edges of ponderosa pine (*Pinus ponderosa*) forests (Sowder and Mowat 1958). A dramatic increase in establishment and density of western juniper in much of the Intermountain West seems to have occurred in the late 1800s and early 1900s (Burkhardt and Tisdale 1969, Adams 1975, Young and Evans 1981). Western juniper woodlands are presently concentrated in central and eastern Oregon, with extensions into northern California, northern Nevada, southwestern Idaho, and eastern Washington (Dealy et al. 1978). Expansion of western juniper into sites originally dominated by mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*) and perennial bunchgrasses in southwestern Idaho was found to be directly related to cessation of fire (Burkhardt and Tisdale 1976). Overgrazing has also been proposed as a factor contributing to increased western juniper density (Dealy et al. 1978).

Effects of increased western juniper frequency and density on associated vegetation are poorly understood. In pinyon-juniper woodlands, increases in frequency and density of trees have been shown to reduce the quantity and diversity of associated species (Dwyer 1975). Pinyon and juniper begin to exert their influence over the understory at the stage of community development characterized by an abundance of seedlings and saplings, and a few vigorous, mature trees (Blackburn and Tueller 1970). In 60–70 years, although height of trees at this point is only double that of shrubs, understory species decline at an increasingly rapid rate. As tree density increases, the understory is yet further reduced (Blackburn and Tueller 1970, Dwyer 1975, West et al. 1979, Tausch et al. 1981, Schott and Pieper 1985). Seed reserves of primary understory species decline and species diversity decreases (Koniak and Everett 1982).

Spatial patterns of understory vegetation may also develop beneath individual woodland trees. Patterns of plant cover relative to

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distance from the bole have been found for singleleaf pinyon (*Pinus monophylla*), Utah juniper (*Juniperus osteosperma*) (Everett and Koniak 1981), and one-seed juniper (*Juniperus monosperma*) trees (Arnold 1964). Such patterns may vary with tree size, as found by Everett et al. (1983) in singleleaf pinyon–Utah juniper stands.

Climax stands of western juniper contain trees of mixed ages, ranging from first-year seedlings to trees several hundred years old, with most individuals in an intermediate age class (Burkhardt and Tisdale 1969). Seral stands are usually composed of predominantly younger age classes with a maximum age of nearly 100 years. Personal observations, as well as data from Driscoll (1964), suggest that as western juniper stands increase in age, size, and density, understory production is reduced and species composition changes. This vegetation suppression by western juniper at particular stages of woodland development has not been closely examined.

This study was begun to determine the relationship between individual trees of various sizes (ages) and the phytomass production of associated vegetation beneath and immediately adjacent to the canopy. Specifically, we wanted to identify phytomass production patterns of associated vegetation relative to western juniper tree size and location within seral stands.

## METHODS

The study area is located 8.8 km southeast of Prineville in central Oregon, on a gentle north-northwest-facing slope. Long-term precipitation in Prineville (elevation 868 m), the nearest recording station, averages 254 mm annually, 89% of which occurs from October to June.

The area is representative of the Juniper Zone described by Driscoll (1964) and is characterized by the dominance of western juniper and associated shrubby vegetation, most commonly Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), and scattered low sagebrush (*Artemisia arbuscula*). Native perennial grasses include Idaho fescue (*Festuca idahoensis*), bottlebrush squirreltail (*Sitanion hystrix*), bearded bluebunch wheatgrass (*Agropyron*

*spicatum*), and Sandberg bluegrass (*Poa sandbergii*). Cheatgrass brome (*Bromus tectorum*) and many forbs, both annual and perennial, comprise the remainder of the herbaceous component.

The study area showed no evidence of fire in the last 100 years and had been used for much of the past decade as pasture, grazed heavily during the winter and early spring. Mixed tree size classes (Burkhardt and Tisdale 1969), continuing recruitment of western juniper seedlings, the presence of locally isolated areas of vigorous bunchgrasses, along with soil characteristics, indicated the area was at an early to mid-seral successional phase.

Study sites at two elevations were selected in this area—one at an elevation of approximately 1140 m and another at 1220 m. Precipitation on each site was measured with U.S. Forest Service rain gauges. Lower site soils were relatively shallow (330 mm), clayey, mesic Aridic Durixerolls, while upper site soils were moderately deep (740 mm), clayey-skeletal, frigid Pacific Argixerolls. The soils, vegetation, fire, and grazing history are typical of the western juniper communities on soils of basaltic origin described by Driscoll (1964). Canopy cover of western juniper, determined using the line-intercept method (Canfield 1941), was 21% on the lower site and approximately 40% on the upper site.

On each site an area representative of general woodland conditions (i.e., tree size and density) was identified and a 50 × 40-m plot arbitrarily placed within it. In each plot all trees were inventoried as to height and canopy diameter and then separated into three canopy diameter size classes—small (1–3 m), intermediate (3–5 m), and large (5–9 m), corresponding to approximate average ages (determined from core samples) of 40, 55, and 75 years, respectively. From each of these three canopy size classes, five trees without overlapping canopies were randomly selected for sampling.

During June and July in both 1983 and 1984, phytomass production in the herbaceous layer was measured. The five individual trees within each size class were used as replications. Production was determined on an individual tree basis by clipping vegetation to ground level in small plots along transects corresponding to the cardinal directions.

Each transect was established within a 90-degree quadrant radiating from the bole of the tree and extending at least 1.2 m beyond the edge of the canopy. Samples were designated into two zones: the canopy zone (from the bole outward to the edge of the canopy) and the intercanopy zone (the area beyond the edge of the crown extending into the open space between tree canopies). Because each interstitial area was of different size and configuration, the intercanopy zone was restricted to an area immediately adjacent to an individual tree's canopy. Plot number and size varied with tree size to insure sampling at least 10% of each of these zones ( $n = 2$  to  $n = 7$ ;  $20 \times 20$ -cm to  $50 \times 60$ -cm plots). Samples were dried at 100 C for 24 hours and weighed. Productivity comparisons were made on the basis of grams of dry matter per square meter.

Data was log-transformed to stabilize variance, and a split-split-plot analysis of variance was used. Main plots were years (1983, 1984) and tree size (small, intermediate, large). Subplots were zones (canopy, intercanopy), and sub-subplots were quadrants (not addressed in this paper). Where interactions were not significant, main effects means were separated using Tukey's w-procedure at  $P \leq .05$  (Steel and Torrie 1980). When interactions were significant, multiple comparisons were made by computing an adjusted comparison-wide probability using the Bonferroni inequality (Miller 1986). All analyses were performed using the Statistical Analysis System (SAS Inc. 1988).

## RESULTS

In 1983 and 1984 total precipitation at Prineville, Oregon, was above the 30-year average, with precipitation on the study sites even higher. On-site precipitation from October to June was 420 mm and 480 mm on the lower site and 454 mm and 494 mm on the upper site for 1983 and 1984, respectively. This compared with 235 mm for the 30-year average at Prineville during the same period.

Production on both sites showed significant between-year differences, as well as year-by-size and year-by-zone interactions (Tables 1, 2). There were no three-way (year-by-size-by-zone) interactions. Total production on the lower slope site, which showed a significant year-by-size interaction (Table 1), was 38.9

$\text{g/m}^2$  in 1983 and 18.3  $\text{g/m}^2$  in 1984. Sandberg bluegrass, bottlebrush squirreltail, cheatgrass, and annual forb production comprised the greatest part of this production on the lower slope site. Production of these individual species was significantly greater in 1983 than in 1984 (Fig. 1).

On the upper slope site, total production was 42.4  $\text{g/m}^2$  in 1983 and 36.2  $\text{g/m}^2$  in 1984 and showed no between-year differences or interactions (Table 2). Species contributing most to total production on the upper slope site were Sandberg bluegrass, Idaho fescue, and perennial and annual forbs. In contrast to the lower slope site, only miscellaneous annual grasses and annual forbs showed any year-to-year differences (Fig. 1); both had significantly greater production in 1984 than in 1983.

Other relationships on both sites were confounded by interactions between main effects (Tables 1, 2). Perennial forb and total production showed significant year-by-size interactions on the lower slope site, while cheatgrass production on the upper slope site had a significant year-by-zone interaction. Because of these interactions and between-year differences in precipitation patterns, we analyzed data by individual years to examine the main effects of tree size and zone.

Tree size had a significant effect on the phytomass production of individual species on both sites (Tables 1, 2). On the lower slope site, production of bottlebrush squirreltail (1983) and perennial forbs (both years) was significantly greater associated with large trees than with small trees (Fig. 2). On the upper slope site, production of bottlebrush squirreltail (1983), bluebunch wheatgrass (1983), cheatgrass (1983), miscellaneous annual grasses (both years), perennial forbs (both years), and annual forbs (1983) was greater associated with large than small trees (Fig. 3). These relationships were reflected in significantly greater total production associated with large than with intermediate and small trees in 1984 (data not shown).

Location relative to the tree canopy also significantly affected production on both sites (Tables 1, 2). On the lower slope site (Table 1) there were significant differences in production between canopy and intercanopy zones for Sandberg bluegrass (both years), bottlebrush squirreltail (1983), bluebunch

TABLE 1. ANOVA results of log-transformed mean phytomass production on the lower slope site.

Species	Year	Year × Size	Year × Zone	1983			1984		
				Size	Zone	Size × Zone	Size	Zone	Size × Zone
Sandberg bluegrass	*	—	—	—	**	—	—	*	—
Bottlebrush squirreltail	**	—	—	*	**	—	*	**	*
Bluebunch wheatgrass	—	—	—	—	**	—	—	**	—
Cheatgrass	**	—	—	—	**	**	—	**	**
Misc. annual grasses	—	—	—	—	—	—	—	—	—
Perennial forbs	*	**	—	**	—	—	*	—	—
Annual forbs	**	—	—	—	—	—	—	**	—
Sagebrush	—	—	—	—	—	—	—	—	—
Total	**	*	—	—	—	—	**	—	*

\*p < .05.  
\*\*p < .01.

TABLE 2. ANOVA results of log-transformed mean phytomass production on the upper slope site.

Species	Year	Year × Size	Year × Zone	1983			1984		
				Size	Zone	Size × Zone	Size	Zone	Size × Zone
Sandberg bluegrass	—	—	—	—	**	—	—	**	—
Idaho fescue	—	—	—	—	—	—	—	—	—
Bottlebrush squirreltail	—	—	—	**	**	—	**	**	**
Bluebunch wheatgrass	—	—	—	**	—	—	—	—	—
Cheatgrass	—	—	**	**	**	—	**	**	**
Misc. annual grasses	**	—	—	**	—	—	**	*	—
Perennial forbs	—	—	—	**	**	—	**	**	—
Annual forbs	**	—	—	**	—	—	—	**	—
Sagebrush	—	—	—	*	—	*	—	—	—
Total	—	—	—	—	—	—	*	—	—

\*p < .05.  
\*\*p < .01.

wheatgrass (both years), and annual forbs (1984). On the upper slope site (Table 2) Sandberg bluegrass (both years), bottlebrush squirreltail (1983), cheatgrass (1983), miscellaneous annual grass (1984), perennial forb (both years), and annual forb (1984) production differed significantly between zones. All species, with the exception of Sandberg bluegrass, had significantly greater production in the canopy than the intercanopy zone (Figs. 4, 5). Sandberg bluegrass production was greater in the intercanopy than in the canopy zone.

Interaction between tree size and zone affected the production of several species (Tables 1, 2). Cheatgrass production on both sites was closely tied to both tree size and zone. The interaction of size and zone was significant both years on the lower slope site and in 1984 on the upper site. On the lower

slope site cheatgrass production in the canopy of large trees was greater than production associated with small and intermediate trees. On the upper slope site production of cheatgrass in both zones was greater associated with large and intermediate trees than with small trees. Bottlebrush squirreltail production also showed significant interaction between size and zone. On both sites (1984) bottlebrush squirreltail canopy production was greater associated with large and intermediate trees than with small trees. These species may have contributed to significantly greater total production in the canopy zone of large versus small and intermediate trees in 1984 on the lower slope site (data not shown). Sagebrush production on the upper slope site in 1983 also showed a significant tree size-by-zone interaction (Table 2). Production of sagebrush was greater in the canopy of large than

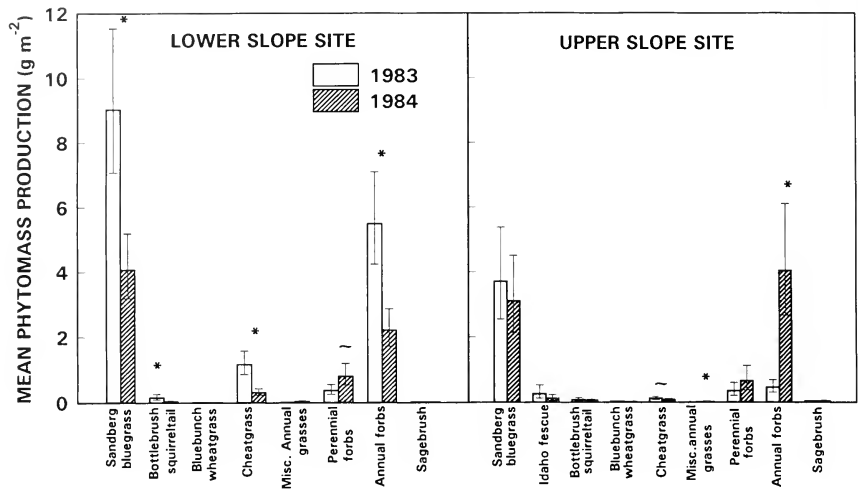


Fig. 1. Mean phytomass production ( $\text{g m}^{-2}$ ) for each species in 1983 and 1984 on the lower slope and upper slope sites. Vertical error bars represent the 95% confidence intervals of the means. (\*) indicates a significant difference between years at  $p < .05$ , ~ indicates a significant year-by-size or year-by-zone interaction,  $p < .05$ .)

in small and intermediate trees, and in the intercanopy of large and intermediate than in small trees.

### DISCUSSION

In this study we found that phytomass production was influenced by both tree size and zone (location relative to the tree canopy). Tree size significantly affected production of most species, especially on the upper slope site (Fig. 3). Bottlebrush squirreltail, bluebunch wheatgrass, cheatgrass, miscellaneous annual grass, and perennial and annual forb production increased as tree size increased. Sandberg bluegrass production, on the other hand, showed no relationship to tree size.

In community level studies, influences of increasing tree size have been found to negatively impact production of associated vegetation. West et al. (1979), working in singleleaf pinyon-Utah juniper communities, found that as tree size increased, understory biomass declined. Blackburn and Tueller (1970) found a reduction in the number of species present in a black sagebrush (*Artemisia nova*) community as pinyon and Utah juniper increased in size and density. Everett et al. (1983) discovered similar negative species-

specific responses to tree size in singleleaf pinyon-Utah juniper communities. In these studies an increase in tree size resulted in greater competition between trees and understory vegetation, with trees outcompeting other species. Conversely, in our study large trees had a positive influence on associated vegetation. On our study site large trees appeared to act as "refuges" for most species, with greatest production associated with the largest tree size.

This importance of microsite in determining species' distribution and production was also reflected in zone relationships. Lower light levels and temperatures, higher humidity, and, possibly, greater nutrient concentrations in the canopy zone (Doeschner et al. 1987) favored production of bottlebrush squirreltail, bluebunch wheatgrass, cheatgrass, miscellaneous annual grasses, and perennial forbs. Sandberg bluegrass production was always greater in the drier, warmer intercanopy zone. These patterns of individual species production relative to tree canopy are not unique to western juniper. Singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) understory plant cover (Everett and Koniak 1981) and one-seed juniper (*Juniperus monophylla*) understory



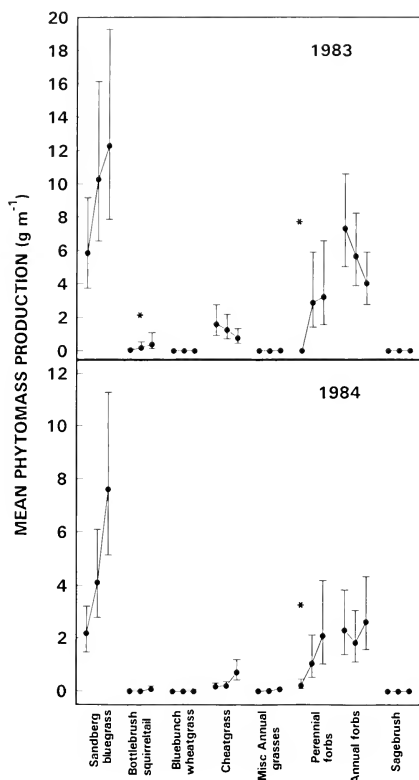


Fig. 2. Mean phytomass production ( $\text{g m}^{-2}$ ) of the three tree size classes in 1983 and 1984 on the lower slope site. For each species, the three tick marks indicate the three tree size classes—small, intermediate, and large. Vertical error bars represent the 95% confidence intervals of the means. (\*) indicates a significant difference between tree size at  $p < .05$ , ~ indicates a significant size-by-zone interaction,  $p < .05$ .)

production (Arnold 1964) were found to occur in species-specific patterns, dependent upon distance from the bole of the tree.

Composition differences in understory species between the upper and lower site may be traced to differences in elevation, the original plant community, soil depth, and, perhaps, long-term grazing. The upper site also appears to receive slightly more October through June precipitation and may be cooler during the growing season (personal observation). The shallower soils of the lower site, in

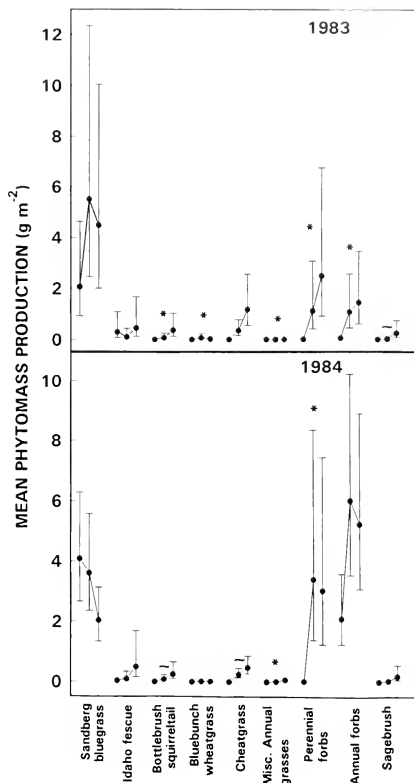


Fig. 3. Mean phytomass production ( $\text{g m}^{-2}$ ) of the three tree size classes in 1983 and 1984 on the upper slope site. For each species, the three tick marks indicate the three tree size classes—small, intermediate, and large. Vertical error bars represent the 95% confidence intervals of the means. (\*) indicates a significant difference between tree size at  $p < .05$ , ~ indicates size-by-zone interaction,  $p < .05$ .)

combination with warmer and drier conditions, supported more squirreltail and cheatgrass. Proximity to a water source may have also resulted in heavier grazing pressure on the lower site. Idaho fescue, on the other hand, was found only on the upper slope site.

Total production tended to be greater and less variable on the upper than on the lower site. Year-to-year differences in precipitation patterns may affect species production more on the lower slope site, where soil depth precludes much storage of soil moisture.

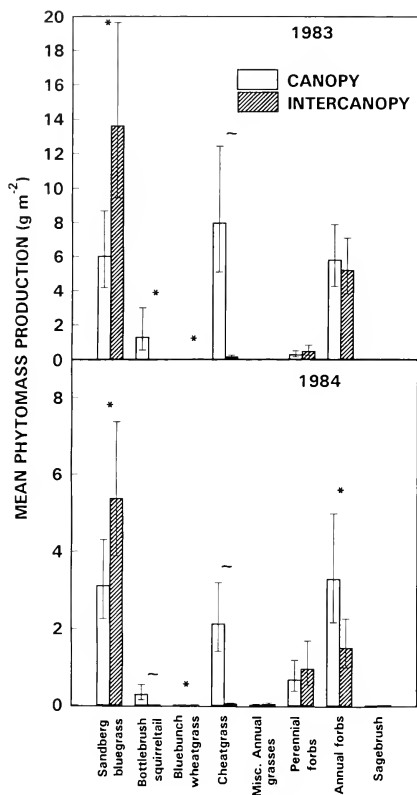


Fig. 4. Mean phytomass production ( $\text{g/m}^2$ ) of the canopy and intercanopy zones in 1983 and 1984 on the lower slope site. Vertical error bars represent the 95% confidence intervals of the means. (\* indicates a significant difference between zones at  $p < .05$ , ~ indicates a significant zone-by-size interaction,  $p < .05$ .)

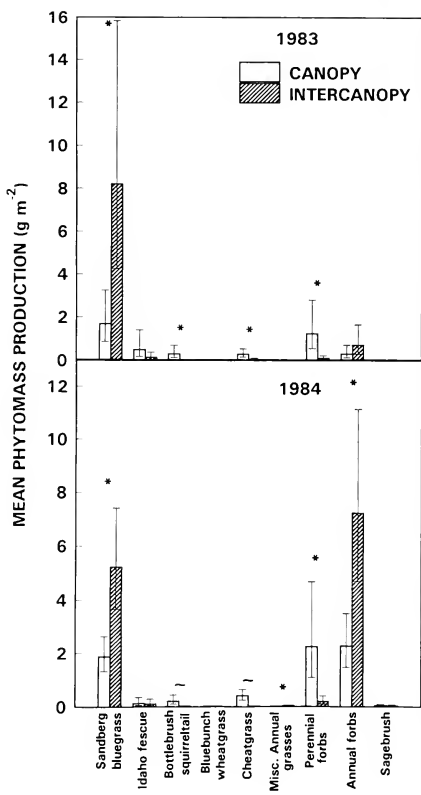


Fig. 5. Mean phytomass production ( $\text{g/m}^2$ ) of the canopy and intercanopy zones in 1983 and 1984 on the upper slope site. Vertical error bars represent the 95% confidence intervals of the means. (\* indicates a significant difference between zones at  $p < .05$ , ~ indicates a significant zone-by-size interaction,  $p < .05$ .)

Spatial and tree size relationships observed in this study indicate the significant role microenvironments play in species distribution and production. As individual trees increase in size (or as western juniper communities progress from tree invasion to closed stands), they exert a greater influence on associated vegetation. Original community dominants appear to become spatially segregated beneath tree canopies of large trees, while less common species, such as cheatgrass, increase across the entire site.

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## PHYSICAL CHARACTERISTICS OF BLUE GROUSE WINTER USE-TREES AND ROOST SITES

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**ABSTRACT.**—Physical characteristics of winter use-trees and roost sites of Blue Grouse (*Dendragapus obscurus*) were studied in northeastern Utah. Blue Grouse selectively roosted in the largest Douglas-fir (*Pseudotsuga menziesii*) trees during the day and subalpine fir (*Abies lasiocarpa*) trees at night. Diurnal and nocturnal roosts were typically adjacent to tree trunks in the lower two-thirds of trees. Nocturnal roosts provided greater canopy and denser shelter than diurnal roosts. Roost site selection was consistent with occupation of favorable microhabitat, particularly at night, and foraging strategy during the day. Timber management strategies should perpetuate large trees within Douglas-fir–subalpine fir habitat in areas occupied by wintering Blue Grouse.

**Keywords:** *Abies lasiocarpa*, *Blue Grouse*, *Dendragapus obscurus*, *Douglas-fir*, *Pseudotsuga menziesii*, *roost sites*, *subalpine fir*, *winter habitat*.

Winter habitat of Blue Grouse in the intermountain region consists of snowbound open stands of conifers on moderately steep to steep upper slopes and ridgetops (Marshall 1946, Cade 1985, Stauffer and Peterson 1985). Douglas-fir is the dominant winter food and may constitute as much as 95% of the diet (Beer 1943, Stewart 1944, Marshall 1946); selectivity for Douglas-fir has been documented from use-availability measures (Cade 1985, Stauffer and Peterson 1986). Douglas-fir sites used most frequently have 45–55% tree cover and are dominated by “wolf” trees (Stauffer 1983, Cade 1985), which are uniquely large with atypical shapes and dense foliage.

Blue Grouse winter habitat relationships are usually described in terms of food habits, although other factors are likely involved. Trees used for diurnal roost sites may be chosen for a favorable microclimate in addition to food (Stauffer 1983, Cade 1985). Presumably, the selection of nocturnal use-trees by Blue Grouse is influenced by microclimatic and protective conditions. The physical characteristics of nocturnal use-trees and roost sites have not been previously described. The objective was to describe the physical characteristics of diurnal and nocturnal use-trees and associated roost sites used by Blue Grouse during winter.

### STUDY AREA

The study area is located on the Cache National Forest in the Bear River Range of the Wasatch Mountains in northeastern Utah. The primary study area is on a north-south ridge 2.5 km east of Logan Peak (USGS, Logan Peak, Utah, 7.5 min quadrangle, 1969) and encompasses approximately 700 ha. The forest is a subalpine fir/Douglas-fir mix with a shrubby undergrowth classified as the *Abies lasiocarpa* climax series–*Pseudotsuga menziesii* phase (Mauk and Henderson 1984). Topography varies from flat ridgetops to steep canyons and includes all aspects. Elevations range from 2500 to 2950 m; the regional mean January temperature is –10 °C, and the mean annual precipitation is 102 cm, with 85% occurring from September through April, the majority as snow (Mauk and Henderson 1984). Snow depth on the study area ranged from approximately 2 m to 3.5 m during the winter of 1985–86. The area is characterized by strong winter temperature inversions that result in temperatures 5–10 °C higher at high elevations than in valley bottoms (Wilson et al. 1975).

### METHODS

The point sample method (Grosenbaugh 1952) was used to inventory vegetation. A

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40-basal-area-factor prism was used because the area was dominated by large trees. The area was inventoried along parallel transects with point samples ( $n = 216$ ) taken at 50-m intervals along transects spaced 65 m apart. Canopy cover at each point was the average of four measurements obtained with a densitometer. Cover readings were taken parallel to the ground at waist level.

Grouse were located by ground searches and captured with a telescopic noose pole (Zwickel and Bendell 1967) when possible. Captured grouse were weighed, classified to sex and age, and fitted with a 25–30 g (<3% body weight) poncho-mounted radio transmitter (Amstrup 1980, Pekins 1988a). Diurnal use-trees and roost sites were found by locating radio-marked and unmarked Blue Grouse from December 1985 to March 1986. Any tree from which a grouse was flushed or observed was considered a use-tree, but a site was categorized as a roost only if a roosting (vs. standing) bird was observed in a nonalarmed state (e.g., crown feathers were not raised). Use-trees were marked immediately, and roost sites were marked the following day.

Nocturnal use-trees and roost sites were identified from visual sightings of radio-marked birds. The general area within a tree in which a grouse roosted was ascertained using a portable receiver and antenna. The tree was then searched with flashlights until the bird was sighted. Sites were then marked and the grouse left undisturbed.

Physical measurements of use-trees included diameter at breast height (dbh) and height. Roost site measurements included roost height, distance from tree trunk, diameter of tree trunk adjacent to the roost site, roosting branch diameter and compass direction, and percent canopy cover. Roost site height was expressed as a percentage of the total height of the tree; both heights were corrected for snow depth. Canopy cover was estimated with a densitometer. Chi-square and  $t$  tests (Steele and Torrie 1980) were used to test for differences in frequency of trees used and in physical characteristics of trees and roost sites. A level of significance was set at .05.

## RESULTS

The average basal area of trees in the study area was 19.5 m<sup>2</sup>/ha. Nearly one-third of

the sample points had no trees or had trees too small to be measured with the prism. Douglas-fir, subalpine fir, and Engelmann spruce (*Picea engelmannii*) represented 51%, 47%, and 2% of the total basal area, respectively. Average canopy coverage was 44%, and an equal number of plots had canopy coverage above and below 50%; 20% had less than 10% cover since openings and forest islands were common.

We identified 270 use-trees (47 nocturnal), of which 267 were fir (Douglas or subalpine), 1 was Engelmann spruce (nocturnal), and 2 were limber pines (*Pinus flexilis*) (diurnal). Use of Douglas-fir and subalpine fir (90% and 70% of the diurnal and nocturnal use-trees, respectively) was greater than expected, based on availability ( $\chi^2 = 127$  and 8.7,  $P < .05$ , respectively). For each species, average dbh of use-trees was greater ( $P < .05$ ) than dbh of the stand average (Table 1). Ninety percent of the Douglas-fir trees used by grouse had dbh >35 cm. Douglas-fir trees used during the day were shorter than those used at night.

Physical characteristics were measured at 161 roost sites (Table 2). Diurnal and nocturnal roost sites were typically located adjacent or close to large tree trunks in the lower two-thirds of trees and were not oriented ( $\chi^2 = 6.1$ ,  $P > .05$ ) in any direction. Nocturnal subalpine roost sites had greater ( $t = 6.91$ ,  $P < .05$ ) canopy cover (91%) than diurnal Douglas-fir roost sites (73%), and more nocturnal than diurnal roosts were adjacent to tree trunks. Seven Douglas-fir nocturnal roosts averaged 85% canopy cover; 5 of these were 1.7 m ( $\pm 1.1$ ) away from the tree trunk.

## DISCUSSION

The study area used by Blue Grouse during winter was dominated by large Douglas-fir and subalpine fir trees in both clumped and open stands. Blue Grouse in Idaho also selected open conifer stands (50:50 ratio of conifer cover to open) dominated by islands of Douglas-fir and subalpine fir (Caswell 1954, Stauffer 1983). Wintering areas in Colorado include dense and open second growth, mature, and old-growth coniferous forests, with an average basal area (20.9 m<sup>2</sup>/ha; Cade 1985) similar to that measured in this study.

TABLE 1. Characteristics of trees used and unused by Blue Grouse during winter, Logan, Utah, 1985–86.

	Douglas-fir (diurnal)					Subalpine-fir (nocturnal)				
	Use-tree			Stand average		Use-tree			Stand average	
	x	SE	n	x	SE	x	SE	n	x	SE
dbh, cm	65.0*	1.4	200	59.1	1.3	47.5*	2.7	32	35.3	1.0
Range	20.0 – 139.7					15.8 – 98.1				
Height, m	15.3*	0.4		19.4	0.4	20.9*	1.3		18.1	0.4
Range	5.7 – 30.2					5.3 – 37.0				

\*Difference ( $P < .05$ ) between use-tree and stand average.

TABLE 2. Physical characteristics of diurnal and nocturnal winter roost sites of Blue Grouse, Logan, Utah, 1985–86.

Characteristic	Douglas-fir roost sites				Subalpine fir roost sites			
	Diurnal (127) <sup>a</sup>		Nocturnal (7)		Diurnal (5)		Nocturnal (22)	
	x	SE	x	SE	x	SE	x	SE
Cover, %	73	2	85	4	91	1	91*	2
Southern hemisphere, %	55		43		0		36	
Lower 2/3 of tree, %	87		100		100		91	
Adjacent to trunk, %	70		14		80		82	
Distance to trunk, m	1.0	0.3 (38)	1.7	1.1 (5)	0.7 (1)		1.4	0.7 (4)
Adjacent trunk dbh, cm	35.5	4.2	40.5	5.8	29.1	13.3	32.5	3.2
Branch diameter, cm	5.8	0.3	5.5	1.2	4.2	1.5	4.2	0.3

<sup>a</sup>Sample size indicated by numbers within parentheses.\*Difference ( $P < .05$ ) between diurnal-used Douglas-fir and nocturnal-used subalpine fir roost sites.

Douglas-fir with atypical growth patterns (larger dbh and shorter height) were selectively used by Blue Grouse as in other wintering areas at similar elevations (Caswell 1954, Stauffer 1983, Cade 1985). The diurnal use of atypical Douglas-firs likely reflects Blue Grouse foraging strategy (Cade 1985). The average dbh of Douglas-fir in our area (65.0 cm) is the largest reported; the average for other intermountain studies is about 50 cm. Subalpine fir trees were preferentially used as nocturnal roost sites in this study area. Blue Grouse in Colorado were often observed flushing to a subalpine fir at dusk after feeding in Douglas-fir or lodgepole pine (*Pinus contorta*) trees (T. E. Remington, personal communication).

The physical characteristics of roost sites we measured indicate that diurnal and nocturnal roost sites provide a favorable microclimate for Blue Grouse. The single exception was that grouse did not consistently roost on branches with a southerly orientation as previously reported (Hoffman 1961). However, 71% of diurnal roosting Blue Grouse observed on the study area were in sunlight (Pekins 1988b).

Moderation of wind speed is the most significant energy-saving characteristic of roost

sites (Walsberg 1985). Wind speed is typically higher at the top of the canopy (Monteith 1973), and wind penetration is reduced as the horizontal structure of the vegetation is widened (Jones 1983). The typical diurnal roost site we identified provided a solid shelter (tree trunk) on one side with encircling, wide coniferous boughs that modify exposure to wind. A typical nocturnal roost site provided a solid shelter on one side surrounded by a dense network of small coniferous branches. Mistletoe often provided proximate dense growth at nocturnal roost sites.

Blue Grouse seldom ate subalpine fir foliage in our study area (<5% of the diet; Pekins, unpublished data), but they likely selected subalpine fir trees for nocturnal roosting because of its associated microclimate. Further, subalpine fir use-trees generally occurred in large, continuous stands, unlike the more variable locations of Douglas-fir use-trees. The roost tree location, large size, and dense growth presumably provided significant wind protection during the night. Measurements within both tree species substantiated that wind speed was consistently lower in subalpine fir (Pekins 1988b).

Bergerud and Gratson (1988) suggested that grouse roosting in conifers affords

protection from avian predators (e.g., Goshawks [*Accipiter gentilis*] and Great Horned Owls [*Bubo virginianus*]) and may serve as an alternative to occupying snow roosts for predator avoidance. They assume neither strategy is consistent with a thermoregulatory hypothesis. However, the energetic advantage for grouse occupying a thermoneutral environment in a snow roost is well documented (Marjakangas et al. 1984, Thompson and Fritzell 1988, Korhonen 1989). Blue Grouse undoubtedly benefit, although remaining vulnerable to avian predators (Goshawks killed several grouse in the study area), while roosting in conifers. However, a switch to subalpine fir from Douglas-firs suggests that energy conservation, not predator avoidance, is the primary determinant of nocturnal roost sites selection.

Forests occupied during winter by Blue Grouse in the intermountain region are frequently of limited commercial value and often in inaccessible areas (Stauffer 1983, Cade 1985). However, some Blue Grouse wintering areas have been cut or are potentially harvestable (e.g., Cade 1985, this study). Selection and patch cuts, which would ensure the presence of large conifers, are recommended management practices in Blue Grouse wintering areas (Cade 1985). Old-age stands at high elevations are irreplaceable within reasonable stand regeneration time. Loss of wintering habitat may severely impact local Blue Grouse populations.

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## HABITAT USE AND FOOD SELECTION OF SMALL MAMMALS NEAR A SAGEBRUSH/CRESTED WHEATGRASS INTERFACE IN SOUTHEASTERN IDAHO

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**ABSTRACT.**—Habitat use and food selection data were collected for deer mice (*Peromyscus maniculatus*), montane voles (*Microtus montanus*), Ord's kangaroo rats (*Dipodomys ordii*), and Townsend's ground squirrels (*Spermophilus townsendii*) near a sagebrush (*Artemisia tridentata*)/crested wheatgrass (*Agropyron cristatum*) interface in southeastern Idaho. Significantly more captures occurred in the native sagebrush habitat than in areas planted in crested wheatgrass or in disturbed sites. Crested wheatgrass, a prolific seed producer, still accounted for over 30% of the total captures. Montane voles and Townsend's ground squirrels (during periods of above-ground activity) used the crested wheatgrass habitat throughout the summer, while deer mice and Ord's kangaroo rats exhibited heavy use after seed set.

**Key words:** small mammals, food selection, habitat selection, deer mice, montane vole, Ord's kangaroo rat, Townsend's ground squirrel.

Research has been conducted on various aspects of the ecology of wildlife residing on and adjacent to the Subsurface Disposal Area (SDA) and one other low-level radioactive waste disposal site on the Idaho National Engineering Laboratory (INEL) in southeastern Idaho. Small mammals were the most frequently occurring wildlife (Arthur and Markham 1983), and densities on the SDA were considerably higher than in adjacent native vegetation types (Groves 1981). Crested wheatgrass planted on the SDA for soil stabilization and hydrologic benefits may provide food for small mammals. A prolific seed producer, it provides a readily available seed source for granivorous rodents in this cold-desert system (Arthur et al. 1986).

In other regions where crested wheatgrass has been planted for livestock grazing use, relative densities and species diversities of small mammals (Reynolds 1980, Reynolds and Trost 1980) were reduced. However, studies conducted on the INEL have shown that crested wheatgrass seedlings are used by small mammals as food sources. Filipovich (1983) reported that deer mice (*Peromyscus maniculatus*), the most abundant rodent on these disposal areas, shifted to heavy use of grass seed when crested wheatgrass went to seed. Reynolds and Arthur (1983) told of a radio-marked deer mouse that would traverse a

linear distance of approximately 250 m each evening from native sagebrush vegetation to the border of the SDA. This animal would then spend the night foraging near the SDA boundary before returning to its burrow at dawn.

This study was undertaken to evaluate the habitat use and food selection of small mammals near a sagebrush/crested wheatgrass interface on INEL. Efforts were concentrated on the four most abundant species of small mammals on the SDA, deer mice, montane voles, Ord's kangaroo rats, and Townsend's ground squirrels.

### METHODS

The INEL is a nuclear energy research facility under the jurisdiction of the U.S. Department of Energy. It occupies approximately 231,000 ha of sagebrush desert on the upper Snake River Plain in southeastern Idaho. Average minimum and maximum daily temperatures in summer and winter range from 10 to 30 C, and -16 to -3 C, respectively. Average annual precipitation is approximately 22 cm (Clawson et al. 1989).

The SDA, a 36-ha portion of the Radioactive Waste Management Complex, has been used for the interment of solid, low-level radioactive waste since 1952. Mixed activation,

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fission, and transuranic radioactive wastes have been disposed at the SDA through use of shallow burial techniques.

Vegetation on the SDA and its perimeter consists primarily of a seeded stand of crested wheatgrass. The native vegetation surrounding the SDA is a predominantly big sagebrush/bluebunch wheatgrass (*A. spicatum*) steppe (McBride et al. 1978). Additionally, several disturbed and unseeded areas are found around the periphery of the SDA. These areas typically support a sparse cover of Russian thistle, cheatgrass (*Bromus tectorum*), and green rabbitbrush (*Chrysothamnus viscidiflorus*) (Arthur 1982).

**HABITAT USE.**—A 6.24-ha (240 × 260-m) live-trapping grid was established on and adjacent to the SDA to examine habitat use patterns. One hundred eighty-two trapping stations were spaced at 20-m intervals on the 13 × 14 grid. Each trapping station consisted of two Sherman live traps baited with a mixture of rolled oats and whole wheat and containing nonabsorbent cotton for bedding.

Each trap station in the live-trapping grid was placed into one of three habitat type categories: native sagebrush/bluebunch wheatgrass steppe; crested wheatgrass; or recently disturbed but unseeded sites consisting of a sparse cover of Russian thistle, cheatgrass, and green rabbitbrush. Categorization was based on visual observation of the vegetative community in which the trap station occurred. Sixty-five (36%), 63 (35%), and 54 (30%) of the 182 trapping stations occurred in native sagebrush vegetation, crested wheatgrass, and disturbed sites, respectively.

Habitat use data were collected in June, July, and August 1984. Each trapping session consisted of seven consecutive nights of trapping during which traps were set prior to sunset and then checked twice nightly. Animals were carried halfway to the next trapping station prior to release to minimize the tendency to immediately reenter known traps (Price et al. 1984). Measures of habitat use were expressed in terms of total captures, captures per 100 trap nights, and percentage of captures occurring in each of the three habitat types.

Chi-square goodness-of-fit tests, including Yates' correction for continuity (Zar 1974), were used to test for differences between numbers of total captures observed versus

expected in each of the three habitat types. Expected values were determined for each species by multiplying the total captures for that species by the percentage of the trap grid occupied by the particular habitat type. Results of the chi-square tests indicated whether habitat selection occurred or if use was determined by availability. Testing for significance was conducted at the  $P < .05$  and  $P < .01$  levels.

**FOOD HABITS.**—Diet composition and seasonal use of crested wheatgrass as a food for deer mice, montane voles, Ord's kangaroo rats, and Townsend's ground squirrels collected near a sagebrush/crested wheatgrass interface were evaluated. Four separate trapping periods were conducted during the year to correspond with different phenological stages of crested wheatgrass. These included June (vegetation lush and green), July (onset of desiccation), August (vegetation severely desiccated and seed set), and January and early March (vegetation dormant with winter conditions prevalent).

Two separate grids were trapped for food habit analysis of small mammals captured near a sagebrush/crested wheatgrass interface. The first grid consisted of two lines of traps in a 25 × 100-m configuration. Trap lines were oriented parallel to and 50 and 75 m from the sagebrush/crested wheatgrass interface in the native sagebrush habitat type. Because montane voles and Ord's kangaroo rats exhibited a high degree of fidelity to the crested wheatgrass and were not captured, the trapping scheme was modified. The second configuration consisted of a 75 × 350-m trap grid established perpendicular to the sagebrush/crested wheatgrass interface so that it overlapped both vegetation types. The grid began 100 m inside the crested wheatgrass and extended 250 m into the sagebrush. Trap stations were spaced at 25-m intervals. This modification also allowed documentation of movements across the sagebrush/crested wheatgrass interface.

Trapping procedures were identical for both grids as follows. Each trapping station consisted of two traps, one Museum Special snap trap and one Sherman live trap. Snap traps were baited with peanut butter while the live traps were either unbaited or baited with a small amount of whole wheat. The traps remained set continuously during trapping

TABLE 1. Total captures of small mammals in each of three habitat types on and adjacent to the SDA, June–August 1984. Significance of chi-square tests between observed versus expected numbers is shown. Captures per 100 trap nights in parentheses.

Habitat type and species	June	July	August	Total
CRESTED WHEATGRASS				
<i>Dipodomys ordii</i>	107 (6.1)	43 (2.4)	40 (2.3)	190** (3.6)
<i>Microtus montanus</i>	62** (3.5)	41** (2.3)	25** (1.4)	128** (2.4)
<i>Peromyscus maniculatus</i>	219** (12.4)	237** (13.4)	339** (19.2)	795** (15.0)
TOTAL	388* (22.0)	321 (18.1)	404* (22.9)	1113** (21.0)
DISTURBED SITES				
<i>Dipodomys ordii</i>	127** (8.4)	45** (3.0)	48** (3.2)	220** (4.9)
<i>Microtus montanus</i>	16 (1.1)	8 (0.5)	3 (0.2)	27** (0.6)
<i>Peromyscus maniculatus</i>	271 (17.9)	264 (17.5)	329 (21.8)	864 (19.0)
TOTAL	414 (27.4)	317 (21.0)	380 (25.2)	1111 (24.5)
NATIVE SAGEBRUSH				
<i>Dipodomys ordii</i>	25** (1.4)	7** (0.4)	7** (0.4)	39** (0.7)
<i>Microtus montanus</i>	5** (0.3)	0** (0.0)	2** (0.1)	7** (0.1)
<i>Peromyscus maniculatus</i>	436** (24.0)	358** (19.7)	498** (27.4)	1292** (23.7)
TOTAL	466 (25.7)	365 (20.1)	507 (27.9)	1338 (24.5)
TOTAL CAPTURES				
<i>Dipodomys ordii</i>	259 (5.1)	95 (1.9)	95 (1.9)	449 (2.9)
<i>Microtus montanus</i>	83 (1.6)	49 (1.0)	30 (0.6)	162 (1.0)
<i>Peromyscus maniculatus</i>	926 (18.2)	859 (16.9)	1166 (22.9)	2951 (19.3)
TOTAL	1268 (24.9)	1003 (19.8)	1291 (25.4)	3562 (23.2)

\* $P < .05$ .

\*\* $P < .01$ .

sessions and were checked at least each morning and evening. Rodents captured in live traps were immediately sacrificed by cervical dislocation.

Diet composition was determined by micro-histological analysis of stomach contents. All analyses were conducted by the Composition Analysis Laboratory at Colorado State University (Sparks and Malechek 1968). Identification of plant and arthropod fragments was made by comparison of microscopic characteristics with reference specimens collected on the INEL. Unidentified species were classified by genus, family, or order. Stomach content composition was reported as the percent relative density (number of points where each item occurred relative to the total number of points in that sample) of plant or arthropod fragments identified in the sample.

## RESULTS

### Habitat Use

A total of 3898 captures of seven species of small mammals in 15,288 trap nights occurred during the summer of 1984. The four species of primary concern accounted for 3562 (91%) (Table 1). Deer mice were the most fre-

quently captured species, accounting for 76% of the total. During the project, 747 deer mice, 106 montane voles, and 95 Ord's kangaroo rats were captured and used in habitat evaluation analyses. Only two Townsend's ground squirrels were caught because of their diurnal activity patterns.

Most animals (1138 or 38%) were caught in the native sagebrush habitat. The fewest captures (1111 or 31%) occurred in disturbed sites, while 1113 (31%) were made in crested wheatgrass (Table 1). Chi-square tests confirmed that the native sagebrush habitat type was used significantly ( $P < .01$ ) more than disturbed sites or crested wheatgrass.

When captures per 100 trap nights were considered (Table 1), the results were different. Again, the highest relative density of small mammals, 28.2 individuals per 100 trap nights, was observed in sagebrush vegetation type. But the amount of use observed in the disturbed sites and crested wheatgrass habitat types was reversed. Disturbed sites accounted for 25.7 captures per 100 trap nights, while the crested wheatgrass had 22.5 captures per 100 trap nights.

Although crested wheatgrass had the lowest relative density of small mammals of any of

the habitat types, all three types received considerable use. Several species of small mammals used this habitat type heavily throughout the summer or seasonally.

Montane voles exhibited a significant ( $P < .01$ ) selection for the crested wheatgrass habitat type and against both disturbed sites and native sagebrush habitat types. Seventy-nine percent of all captures of montane voles occurred in crested wheatgrass and 17% in disturbed sites. Thus, 96% of the montane vole captures occurred in habitat types created by waste management operations.

Ord's kangaroo rats used both disturbed sites and crested wheatgrass significantly ( $P < .01$ ) more and native sagebrush significantly ( $P < .01$ ) less than would be expected. Over 42% of all captures of kangaroo rats occurred in the crested wheatgrass habitat, while 49% of the captures occurred in disturbed sites. So, as with montane voles, a large percentage of all captures (91%) of kangaroo rats was recorded in habitat types resulting from alteration of the native sagebrush vegetation type.

Deer mice used the sagebrush habitat significantly ( $P < .01$ ) more than the disturbed and crested wheatgrass habitats. Nearly 44% of all captures of deer mice occurred in sagebrush, while disturbed sites and crested wheatgrass accounted for 29% and 27%, respectively. However, use of crested wheatgrass increased as the summer progressed, and by August more captures occurred in crested wheatgrass than in disturbed sites (Table 1).

#### Food Habits

Although an attempt was made to collect at least 10 individuals of each of the four small mammal species during each trapping session, it was not always possible because some animals were trap shy and some were found to have empty stomachs. There was a high degree of similarity in the food habits of animals collected from both trap grids. Therefore, data were pooled to evaluate food habits of small mammals collected near a sagebrush/crested wheatgrass interface.

**DEER MICE.**—Stomach contents of 72 deer mice were analyzed from August 1983 through June 1985. Crested wheatgrass appeared to be relatively unimportant as a food item except during periods after the grass had gone to seed. Lepidoptera larvae ranked as

the most important item in diets of deer mice collected in June and constituted 71% of the fragments identified in the samples. Small amounts of crested wheatgrass were present in the samples collected in July. However, it ranked as the eighth most frequently consumed food item and composed less than 1% of the diet. Gramineae seed was the most important food item in July, making up 66% of the diet of deer mice.

There was a pronounced shift to the use of crested wheatgrass by deer mice in August. In this month, crested wheatgrass was found in 22 of the 29 (76%) animals collected; thus, it ranked as the most important food item. Coleoptera adults and Orthoptera ranked second and third, comprising 19 and 10%, respectively.

Ten deer mice were collected in January and 10 in March. Unidentified seed was the most important food item, comprising 96% of the food in these animals. Crested wheatgrass was not identified in any of these samples.

**MONTANE VOLES.**—Stomach contents of 20 voles were evaluated. Crested wheatgrass was the major food item for montane voles throughout the summer. Samples from all voles collected in June, July, and August contained crested wheatgrass.

**ORD'S KANGAROO RATS.**—Food habits of 25 kangaroo rats were evaluated. Eight animals were collected in June 1985, 5 in July 1984, and 12 in August 1983 and 1984. Four of the 8 (50%) kangaroo rats collected in June had been feeding on crested wheatgrass; thus, crested wheatgrass was the fourth most important food item. The three items that were eaten in higher percentages were pollen (33%), unidentified arthropods (18%), and plant parts from the family Compositae (16%).

In July all five animals collected had eaten crested wheatgrass. At this time crested wheatgrass ranked as the most important food item, making up 82% of the diet of these animals. Twelve animals were collected in August, and again crested wheatgrass was identified in every sample. It accounted for 91% of the diet in animals this month.

**TOWNSEND'S GROUND SQUIRRELS.**—Seasonal activity of the Townsend's ground squirrel appeared to be closely correlated to the availability of crested wheatgrass in its lush state. Eighty percent (8 of 10) of the ground squirrels trapped in June had used crested

wheatgrass as a food source. Only one ground squirrel was trapped in July. Stomach contents of this individual consisted of only two items: crested wheatgrass (9%) and gramineae seed (91%).

#### DISCUSSION

Analysis of habitat use and food habits of small mammals around the SDA indicated that the crested wheatgrass habitat type was frequently utilized. Resident animals used crested wheatgrass as a food item, and seeds appeared to attract transients. The percentages of total captures of small mammals occurring in each of the three habitat types were as follows: native sagebrush vegetation (37%), disturbed and unseeded sites (33%), and crested wheatgrass (30%) (Table 1). These results were similar to those of Reynolds (1980) but were opposite those reported by Groves (1981), who found that crested wheatgrass received the most use followed by disturbed sites and then native sagebrush vegetation. Groves (1981) captured higher numbers of small mammals in the crested wheatgrass than in the other two habitat types. However, montane voles were at a high point in their population cycle at the time the earlier study was conducted, which probably accounts for the differences in results. Our results indicated that although crested wheatgrass had the lowest density of small mammals of any of the habitat types, it received considerable use. Several species of small mammals used this habitat type heavily either throughout the summer or seasonally.

Groves (1981) also reported that the densities he found in both the crested wheatgrass and native sagebrush habitat types were considerably higher than had been reported in the literature for similar vegetation types in other areas. This may have been due to the diversity of the area with three distinctive habitat types and the large amount of "edge," all in a rather confined area.

Montane voles were more dependent upon the crested wheatgrass habitat type than any other species captured during the study. Results of all small mammal studies conducted on the INEL have indicated montane voles were restricted almost exclusively to crested wheatgrass communities (Allred 1973, Reynolds 1980, Filipovich 1983, Groves

and Keller 1983). Voles are typically herbivorous, but little has been reported on specific food habits for this species. Food habit analysis conducted during this study showed crested wheatgrass to be the dominant food item for montane voles on the INEL. All 19 animals captured during the summer months had crested wheatgrass in their stomachs.

Use of crested wheatgrass by kangaroo rats was substantial. This would be expected since kangaroo rats are heteromyids, and crested wheatgrass is such a prolific seed producer. Groves (1981) hypothesized that the enhanced seed supply provided by crested wheatgrass may have accounted for the high number of kangaroo rat captures in this habitat type. Most studies of the food habits of Ord's kangaroo rat have found that this animal is primarily herbivorous/granivorous, eating large amounts of seeds along with the succulent leaves of grasses, forbs, and shrubs, and with arthropods being infrequently consumed (Johnson 1961, Flake 1973, Best and Hoditschek 1982, Kochler 1988). Food habits of kangaroo rats captured near the sagebrush/crested wheatgrass interface we studied fit these broad guidelines. Crested wheatgrass was eaten throughout the summer, but its importance increased as the summer progressed. Crested wheatgrass made up 82% of the food intake in July and 91% in August. This shift to heavy use of crested wheatgrass corresponded to the time of seed set by this grass.

Deer mice are omnivorous, their food habits generally reflecting the local availability of food items (Johnson 1961). Other studies involving food habits of deer mice in southern and southeastern Idaho have found that these rodents rely heavily on arthropods, especially Coleoptera adults and Lepidoptera larvae (Halford 1981) in spring and early summer, followed by a shift to plant material in July and August (Johnson 1961, Filipovich 1983). Our results are consistent with these findings. Crested wheatgrass varied seasonally in importance as a food item. It was relatively unimportant in June, when deer mice consumed various arthropods, and was heavily used later in the summer. The shift to crested wheatgrass in July and August corresponded to the time of summer when the grass set seed.

Food habit studies on Townsend's ground squirrels have reported that these animals

feed mostly on succulent green vegetation (Alcorn 1940, Johnson 1961), especially grasses (Johnson 1977, Smith and Johnson 1985). Both Scheffer (1941) and Johnson (1977) noted that the aboveground activity of Townsend's ground squirrels was highly correlated to the presence of succulent green vegetation. This was also noticed around the SDA. Ground squirrels were present and active early in the spring until about July, when the crested wheatgrass started to desiccate. At this time the animals would go into torpor until the following spring. Johnson (1977) reported that the primary food item of Townsend's ground squirrels on the Hanford Reservation in eastern Washington was Sandberg bluegrass (*Poa sandbergii*); in southern Idaho, cheatgrass provided most of the forage consumed (Smith and Johnson 1985). In both cases the primary food eaten by Townsend's ground squirrels was also the primary grass species on the study area. Crested wheatgrass was the most heavily used food item by ground squirrels around the SDA, making up the bulk of the diets of the ground squirrels analyzed. It was also common to observe ground squirrels feeding on crested wheatgrass, and freshly cut stems were often found in active burrow entrances.

The presence of crested wheatgrass affected small mammal community structure around the SDA by influencing which species were present and their relative densities. Montane voles, Ord's kangaroo rats, and Townsend's ground squirrels exhibit early colonization characteristics after a disturbance. These species, which are either absent or uncommon in the predominant native vegetative types, now compose a large portion of the small mammal community in the SDA environs. Other species, such as deer mice, have adapted to certain components of the introduced vegetation type, specifically the use of crested wheatgrass as a food source.

Although the crested wheatgrass habitat type was used less than either of the other two habitat types, more than 30% of the total captures of small mammals occurred there. Deer mice, Ord's kangaroo rats, and Townsend's ground squirrels used the crested wheatgrass habitat heavily seasonally. Montane voles used the habitat throughout the summer. The use of crested wheatgrass as a food source appeared to be a key element in attracting

small mammals to this habitat type. Crested wheatgrass does influence the type of small mammal community and the densities of these animals. Thus, this unnatural community has an impact on the total diversity of wildlife in the area.

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## EFFECTS OF CONVICT CICHLIDS ON GROWTH AND RECRUITMENT OF WHITE RIVER SPRINGFISH

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**ABSTRACT.**—Observations of changes in population density of native White River springfish (*Crenichthys baileyi*) in Pahranaagat Valley led to the following hypothesis: introduced convict cichlids (*Cichlasoma nigrofasciatum*) cause reduced growth and recruitment; cover reduces the magnitude of the effect. The hypothesis was tested by establishing sympatric and allopatric groups of the two species in experimental aquaria with and without cover. Change in volume ( $\pm$  mass) and length of the two species over a three-month period in spring 1986 and 1987 was measured and analyzed using  $2 \times 2$  factorial analyses. Convict cichlids caused reduced growth and eliminated recruitment of springfish under the experimental conditions. Cover did not influence growth but positively affected recruitment of springfish in allopatry. It is likely that a portion of the reduced springfish population densities in nature can be attributed to adverse effects from introduced cichlids.

*Key words:* exotic species, competition, springfish, population control.

Introduced fishes have been implicated in the decline and/or extinction of native fishes throughout the world. Numerous anecdotal accounts have documented adverse effects, but few have identified the causative mechanism (Schoenherr 1981, Taylor et al. 1984). Moyle et al. (1986) noted that introduced fishes may (1) eliminate native fishes, (2) reduce their growth and survival, (3) change their community structure, or (4) have no effect. Meffe (1985) concluded that elimination of native by exotic fishes in southwestern U.S. is frequently attributable to predation. Schoenherr (1981) demonstrated that competitive interactions with exotic species can reduce survival and produce changes in community structure. Replacement of desert pupfish (*Cyprinodon macularius*) by redbelly tilapia (*Tilapia zilli*) in an irrigation drain near the Salton Sea was attributed by Schoenherr (1985, 1988) to interference with normal behavior patterns. Bestgen and Probst (1987) proposed that reductions of native fish populations in the Southwest, heretofore attributed to interactions with introduced red shiner (*Cyprinella lutrensis*), were more likely due to habitat degradation resulting in elimination of natives from habitats which were then occupied by the alien species. Jennings and Saiki (1990) suggested that a com-

plementary distribution between red shiner and native fishes in the San Joaquin Valley, California, may represent just the first stage in colonization by red shiner. Deacon (1988) reported that after about 20 years of maintaining a complementary distribution, red shiner suddenly expanded its range upstream and, perhaps aided by an introduced parasite (Heckmann et al. 1986), nearly replaced the indigenous woundfin (*Plagopterus argenteus*) in the Virgin River of Utah, Arizona, and Nevada. Introduced fishes obviously interact in complex and variable ways with native species.

In Pahranaagat Valley, Nevada, one population of White River springfish (*Crenichthys baileyi*) was eliminated by nonnative largemouth bass (*Micropterus salmoides*) predation; and two populations were severely depressed, apparently by interaction with convict cichlids (*Cichlasoma nigrofasciatum*), shortfin mollies (*Poecilia mexicana*), sailfin mollies (*P. latipinna*), and mosquitofish (*Gambusia affinis*) (Courtenay et al. 1985). The present study was designed to examine mechanisms that may have caused the observed population reductions. Our hypothesis was that both growth and reproduction of Hiko White River springfish (*C. b. grandis*) are depressed by interactions with convict cichlids and enhanced by cover.

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TABLE 1. Mean volumes (ml) of springfish and cichlids at the beginning (initial) and end (final) of the experimental periods. Numbers in parentheses are one standard deviation.

	Springfish				Cichlids			
	Exp. 1		Exp. 2		Exp. 1		Exp. 2	
	Initial mean	Final mean	Initial mean	Final mean	Initial mean	Final mean	Initial mean	Final mean
Allopatric/ cover	.253 (.152)	.614 (.247)	.461 (.194)	.761 (.223)	1.79 (.847)	2.77 (1.50)	2.09 (1.30)	3.37 (2.41)
Allopatric/ no cover	.256 (.113)	.529 (.204)	.453 (.171)	.776 (.197)	1.07 (.540)	3.23 (1.30)	2.34 (.481)	4.36 (2.57)
Sympatric/ cover	.503 (.154)	.619 (.150)	.553 (.186)	.749 (.189)	.973 (.569)	2.69 (1.44)	2.10 (.987)	4.09 (1.52)
Sympatric/ no cover	.340 (.162)	.523 (.168)	.534 (.210)	.735 (.254)	1.21 (.427)	2.58 (1.18)	1.66 (.576)	4.48 (2.05)

## METHODS

The following experiments were conducted in March–May 1986 (experiment 1) and 1987 (experiment 2). Springfish and cichlids were kept in separate 208-liter stock aquaria for three months in 1986 and one month in 1987 prior to introduction into experimental aquaria. Experimental fish were weighed (volume displacement), measured (total length [TL], mm), and sexed at the beginning and end of the 63-day experimental period (Table 1). Volume displacement and TL were used to minimize trauma from handling. Allopatric groups containing five pairs of springfish or five pairs of cichlids were established in each of two 76-liter aquaria with and without cover. Sympatric groups, each containing three pairs of springfish and two pairs of cichlids, were established in each of two aquaria with and without cover. Cover consisted of assorted rocks and plastic plants, all used in approximately equal amounts. Commercial "spawning grass" was placed in all aquaria to encourage spawning. Fish were fed Tetra-min® Staple Food at a rate of approximately 6.0% body mass twice daily to ensure that food was not a limiting factor. All aquaria were maintained at 23–26 C. One sympatric/no cover aquarium in 1986 suffered a heater malfunction and was terminated. Biological filtration was utilized in experimental aquaria: under-gravel filtration in 1986, biological-sponge filtration in 1987. The stock aquaria were filtered with outside power filters. Seventy-five percent of the water in each aquarium was changed weekly. Observations of chasing behavior were made daily for a one-minute period per aquarium. Fin and body damage was also recorded.

A series of  $2 \times 2$  factorial analyses (Montgomery 1984, Chapter 7) was used to examine the influence of sympatry/allopatry and cover/no cover on growth in volume (mass), TL, number of chases, and extent of fin damage for each species. Significance of differences (at 5% significance level) is summarized in ANOVA tables.

## RESULTS

Data on increases in volume and TL produced the same analytical results for both springfish and cichlids; only the analyses for volume are presented (Table 2). Springfish in allopatric groups grew more rapidly than they did when cichlids were present. Cover had no significant effect, but a slight interaction between sympatry/allopatry and cover/no cover may mask the main effect of cover on growth. If so, cover has a slightly negative effect. For cichlids, higher mean growth by sympatric groups was significant, but cover did not influence growth and there was no interaction between the two factors (Table 2).

Chasing by cichlids was nearly all intra-specific and caused no detectable fin damage to springfish. Among cichlids (Table 3), the two factors, sympatry/allopatry and cover/no cover, had no significant effect on aggressive behavior as measured by chasing or fin damage. Nevertheless, cichlids in experiment 2 were significantly more aggressive than in experiment 1. During experiment 2, all springfish in one sympatric tank without cover were found dead five days before experiments were terminated. We attribute this to aggressive behavior by a nesting pair of cichlids. The dead fish were intact and were weighed,

TABLE 2. Average increase in volume (ml) of springfish and cichlids fed at 12% body weight per day for 63 days (I = increase in volume; n = number of fish).

	Allopatric				Sympatric			
	Cover		No cover		Cover		No cover	
	I	n	I	n	I	n	I	n
EXPERIMENT 1								
Springfish	.36	10	.27	10	.12	12	.23	12
Cichlids	1.19	10	1.80	8	1.72	8	2.37	7
EXPERIMENT 2								
Springfish	.30	10	.32	10	.20	12	.17	6
Cichlids	1.28	10	1.29	7	1.99	8	2.2	6

Analysis of variance of growth data (ml) for springfish and cichlids. Factor A is sympatry/allopatry; factor B is cover/no cover.

Source	d.f.	Springfish		Cichlids	
		MS	F	MS	F
A	1	0.0351125	17.453416**	0.9248	19.9957**
B	1	0.0000125	0.006211	0.2738	5.9200
AB	1	0.0028125	1.397515	0.0072	0.1557
Error	4	0.0020125		0.04625	
Total	7	0.0065696		0.19869	

\*\*significant at the 5% level

TABLE 3. Mean number of intraspecific chases by cichlids per observation period and percentage of cichlids sustaining fin damage during the experimental period (experiment 1 results from Tippie and Deacon 1987).

	Chases		Fin damage	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2
Sympatric, no cover	0.64	1.9	87.5	100
Allopatric, no cover	0.70	6.6	60.0	100
Sympatric, with cover	0.71	5.3	62.3	100
Allopatric, with cover	0.41	9.5	50.0	90

Analysis of variance. Factors = four combinations of treatments: block = experiments 1 and 2.

Source	d.f.	Chases		d.f.	Fin damage	
		MS	F		MS	F
Factors	3	4.6959	0.8939	3	189.5883	2.1084
Block	1	54.2882	10.3349**	1	2119.0050	23.5650**
Error	3	5.2529		3	89.9217	
Total	7	64.2370		7	2398.515	

\*\*significant at the 5% level

measured, and included in the analysis despite a 58- rather than a 63-day growth period.

Chasing by springfish was also more prevalent in experiment 2 (Table 4) but resulted in relatively little fin damage. Most chases were more likely attributable to mating behavior than to aggression.

Reproduction by both species was variable (Table 5). Springfish produced no young during or after the experimental periods in any tank with sympatric cichlids. In contrast, springfish eggs and/or fry were observed at

some time during, or following, the experimental period in all allopatric tanks. Fry were present in one of two allopatric aquaria at termination in experiment 1, but not in experiment 2; however, 14 days after removal of experimental animals, newly hatched springfish appeared in allopatric aquaria in experiment 2.

## DISCUSSION

We conclude that convict cichlids can have a significant adverse effect on growth and

TABLE 4. Mean number of intraspecific chases by springfish per observation period and percentage of springfish sustaining fin damage during the experimental period (experiment 1 data from Tippie and Deacon 1987).

	Chases		Fin damage			
	Exp. 1	Exp. 2	Exp. 1	Exp. 2		
Sympatric, no cover	0.32	5.1	0	0		
Allopatric, no cover	0	10.8	0	20		
Sympatric, with cover	0.15	4.9	0	0		
Allopatric, with cover	0	7.9	0	0		
Analysis of variance. Factors = four combinations of treatments; block = experiments 1 and 2.						
Source	Chases			Fin damage		
	d.f.	MS	F	d.f.	MS	F
Factors	3	3.3585	0.8422	3	50	1.0
Block	1	101.7451	25.5121**	1	50	1.0
Error	3	3.9881		3	50	
Total	7	109.0917		7	150	

\*\*significant at the 5% level

TABLE 5. Reproduction occurring during the experimental period: # = number of tanks in that category containing eggs or fry at some time during or after the experimental period; N = number of fry surviving at termination; T = number of fry appearing following termination.

	Allopatric						Sympatric					
	Cover			No cover			Cover			No cover		
	#	N	T	#	N	T	#	N	T	#	N	T
Springfish	2	11	4	2	0	9	0	0	0	0	0	0
Cichlids	1	49	0	0	0	0	1	0	0	2	99	0

recruitment of White River springfish under the experimental conditions. It seems probable that the lack of recruitment by springfish living sympatrically with cichlids results from cichlid predation on springfish eggs and fry. Presence or absence of cover had no statistically identifiable influence on growth of either species. It did positively affect springfish recruitment, but not that of cichlids. Cichlid aggression is largely intraspecific; however, when cichlids are guarding the nest, aggression can be lethal to adult springfish. Faster growth by cichlids in sympatric experimental populations may be due to their smaller number and biomass in those tanks rather than to a salubrious interspecific relationship. Conversely, springfish grew faster in allopatric aquaria in spite of higher density.

The above conclusions help interpret conditions observed in natural populations. Introductions of convict cichlids into Ash Spring in 1965 and Crystal Spring in the 1970s were closely followed by sharp drops in their respective springfish populations (Courtenay et al. 1985). Reduced growth and recruitment might well produce that result.

More recently, however, Hiko Spring added a puzzling variation to this seemingly straightforward explanation. Following elimination of springfish by largemouth bass and subsequent disappearance of bass from the spring, springfish were reintroduced. The day successful recruitment was confirmed, a few convict cichlids were observed (Baugh et al. 1985). We predicted expansion of both populations, followed by a decline in springfish numbers. The expansion occurred, but the decline did not (Deacon, unpublished data), and we therefore suspected that additional factors might be contributing to low springfish populations at Ash and Crystal springs.

At Ash Spring, elevated ammonia and nitrite levels, apparently leading to increased susceptibility of springfish to bacterial infection from *Pseudomonas* and *Aeromonas*, are factors that may contribute to low population numbers (Taylor et al. 1990). The U.S. Bureau of Land Management, following notification of the problem, took steps to remove cattle. The result was a decrease in contaminants and an increase in densities for all fish species (Taylor et al. 1990). Springfish density

nonetheless remains below levels recorded prior to introduction of cichlids and mollies (Courtenay et al. 1985).

No likely alternative explanation for low springfish populations has been identified at Crystal Spring. It would seem prudent to attempt to discover whether agricultural chemicals or other potentially toxic materials or practices are associated with manipulation of the waters for irrigation. None is apparent.

Maintenance of an abundant springfish population at Hiko Spring for three years indicates that sympatry with introduced convict cichlids, while perhaps stressful, need not invariably result in scarcity of the native species. Our results demonstrate that convict cichlids can depress growth and recruitment of springfish and, under some circumstances, may cause mortality of adults. Those may be the primary causes of low populations at Ash and Crystal springs. At Hiko Spring, however, springfish are to date maintaining essentially natural population densities despite the presence of convict cichlids, mollies, and mosquitofish.

It remains unclear why the springfish population at Hiko Spring should be responding differently from those at Ash and Crystal springs. The interaction is obviously more complex than predation on larvae or depression of growth. Any or all of the following factors may be important: (1) habitat complexity, (2) differences in resource availability, (3) escape cover for larvae, (4) selection of spawning sites, or (5) other behavioral responses developed by populations of springfish and cichlids upon becoming established in a new habitat simultaneously. Clearly, a simple predator-prey model is insufficient to explain variations in springfish population densities resulting from introductions of other species.

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## NEST-SITE SELECTION BY SAGE THRASHERS IN SOUTHEASTERN IDAHO

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**ABSTRACT.**—Nest sites selected by Sage Thrashers (*Oreoscoptes montanus*) in southeastern Idaho were characterized and compared with available habitat. Microhabitats within 5 m of nests had taller and more aggregated shrubs and less bare ground than the study area in general. Big sagebrush (*Artemisia tridentata wyomingensis*) plants used for nesting were taller than average available shrubs, had greater foliage density, were more often living, and more frequently had branches and foliage within 30 cm of the ground. Nest placement was specific with respect to relative nest height and distance from the top and perimeter of the support shrub. Sage Thrashers disproportionately used easterly exposures and underused westerly exposures for their nests.

**Key words:** Sage Thrasher, big sagebrush, shrubsteppe, Idaho, nest-site selection.

Choice of nest sites represents habitat selection on a small spatial scale (e.g., MacKenzie et al. 1982, Stauffer and Best 1986, Bekoff et al. 1987). Availability and suitability of nest sites may govern the composition of bird communities and may structure species-habitat relationships as much as do the availability of food and other resources (Martin 1988). Presumably, patterns of nest-site selection have evolved as a result of selective pressures that have maximized nesting success. In particular, predation (e.g., Murphy 1983, Belles-Isles and Picman 1986) and microclimate (e.g., Pleszczyńska 1978, Ferguson and Siegfried 1989) have been implicated as major agents in molding nest-site selection strategies.

The Sage Thrasher (*Oreoscoptes montanus*) is a common breeding bird in sagebrush-shrubsteppe communities of the western United States (Wiens and Rotenberry 1981). Previous studies of nest-site selection by Sage Thrashers (Reynolds and Rich 1978, Rich 1978, 1980, Reynolds 1981) were limited in that only a few parameters (e.g., nest height, substrate height) were investigated. Our objective was to provide a more thorough analysis of Sage Thrasher nest-site selection, including characterization of nest-site microhabitat, nest substrates, and nest placement within substrates. Further, we measured aspects of available habitat with which to compare nest sites.

### STUDY AREA AND METHODS

The study area, consisting of 25 ha of sagebrush shrubsteppe on the upper Snake River plain 11 km south of Howe, Idaho, is administered by the U.S. Department of Energy as part of the Idaho National Engineering Laboratory (INEL). Vegetation is dominated by big sagebrush (*Artemisia tridentata wyomingensis*), green rabbitbrush (*Chrysothamnus viscidiflorus*), and scattered bunchgrasses. Forbs are sparse and ephemeral, litter accumulations are scant, and much of the ground is bare. In 1980, four 6.25-ha plots (250 m × 250 m) were established and gridded throughout at 25-m intervals with steel stakes affixed with colored plastic flagging.

Data were collected during the breeding seasons of 1980–1984. Nests were located by using a rope-drag technique (Petersen and Best 1985) to flush adults from their nests. Nests also were discovered by observing adults feeding young, and many nests were found incidental to other activities. Each year several nests were discovered after being abandoned, and these were included in the sample. Nests that had deteriorated or were suspected to have been built before the current year were excluded.

Habitat characteristics of each plot were quantified in June each year by using 20 × 50-cm quadrats (Daubenmire 1959) and line intercept (Canfield 1941). Each year one to

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four quadrats were placed 2.5 or 5 m from each grid marker (in different locations each year); percent coverage of rabbitbrush, grasses, forbs, litter, and bare ground was estimated. Additionally, the height of all sagebrush plants included totally or partially within quadrats was recorded, and the condition of each sagebrush plant was noted as dead, 25%, 50%, 75%, or 100% living. We also qualitatively estimated density of foliage on the living portions of shrubs as low, intermediate, or high. Canopy continuity (presence or absence of gaps more than 20 cm across) of each sagebrush plant was recorded, and the profile (presence or absence of any branches or foliage within 30 cm of the ground) of sagebrush plants greater than 40 cm tall was noted.

Canopy coverage and dispersion of sagebrush were estimated by line intercept. Each year 10–25 samples were taken near grid markers on each plot, different grid markers being used each year. These samples were regularly spaced to provide an even distribution of sampling effort across the plot. For each sample we recorded line intercept of sagebrush and distance between adjacent sagebrush plants that were intercepted along a 5-m tape extending in each of the four cardinal compass directions. For each sample the coefficient of variation of intershrub distances was used as an index of dispersion; the greater the index, the more clumped the shrubs. We averaged the habitat data (exclusive of individual shrub measurements) for each grid marker and used the grid markers as observational units in statistical analyses. For individual shrub measurements (height, condition, etc.), the shrubs were the observational units.

To characterize actual nest sites, we recorded the same data for shrubs supporting a nest as for those occurring within quadrats. We also estimated canopy coverage and dispersion of sagebrush along a 5-m tape extending from the nest in each of the four cardinal compass directions. Further, we recorded the height of each sagebrush plant intercepted. From 1981 to 1984 we estimated coverage of rabbitbrush, grasses, forbs, litter, and bare ground in  $20 \times 50$ -cm quadrats placed 2.5 and 5 m from each nest in each of the four cardinal directions. To minimize the potential confounding effects of vegetation change occurring between the time of nest initiation and

our measurements, we took the measurements of rabbitbrush, grasses, forbs, litter, and bare ground soon after a nest had been located. However, these measurements were not recorded for nests abandoned before being located. Data were averaged for each nest so that nests were the observational units in statistical analyses. We also recorded the following measurements: (1) height of each nest (ground to nest rim), (2) distance from the nest rim to the top of the support shrub, (3) shortest horizontal distance from the center of the nest to the perimeter of the support shrub, and (4) compass orientation of the nest relative to the center of the support shrub. We calculated relative nest height as the ratio of nest height to the height of the support shrub and expressed as a percentage.

*T* tests and chi-square analyses were used to compare nest-site features with those of the study area in general. For most *t* tests, variances did not differ significantly between the two groups. When variances differed, we used the *t'* test (Sokal and Rohlf 1969: 374–375), which relaxes the assumption of variance homogeneity. There were few significant variations among years in nest-site features used by thrashers or in habitat features on the study area. Accordingly, data were pooled for all years.

## RESULTS

### Nest-Site Microhabitat

Sage Thrashers chose nesting areas in which sagebrush plants were significantly taller and more clumped than on the study area in general (Table 1). Percent coverages of sagebrush, rabbitbrush, grasses, forbs, and litter within 5 m of thrasher nests were slightly greater than those on the study area in general. Although none of these patterns was significant, their cumulative effect resulted in significantly less bare ground near nests than on the rest of the study area.

### Nest Substrates

All nests were located in or beneath (on the ground) sagebrush plants. Shrubs selected for nesting averaged significantly taller than those representative of the study area ( $t = 15.7$ ,  $df = 5079$ ,  $p < .001$ ). Moreover, the range of shrub sizes used for nesting was much narrower than that of the available shrubs

TABLE 1. Habitat characteristics within 5 m of Sage Thrasher nests and on the study area in general ( $\bar{x} \pm SD$ ).

Variable	Near nests		Study area
Sagebrush height (cm)	49 $\pm$ 12 (53) <sup>a</sup>	<sup>a,b</sup>	41 $\pm$ 18 (5025)
Sagebrush dispersion <sup>c</sup>	86 $\pm$ 19 (53)	*	77 $\pm$ 22 (401)
Sagebrush coverage (%)	23 $\pm$ 10 (53)		22 $\pm$ 11 (401)
Rabbitbrush coverage (%)	6 $\pm$ 4 (34)		5 $\pm$ 7 (484)
Grass coverage (%)	9 $\pm$ 9 (34)		8 $\pm$ 9 (484)
Forb coverage (%)	4 $\pm$ 7 (34)		3 $\pm$ 5 (484)
Litter coverage (%)	7 $\pm$ 3 (34)		6 $\pm$ 6 (484)
Bare ground (%)	50 $\pm$ 12 (34)	*	55 $\pm$ 21 (484)

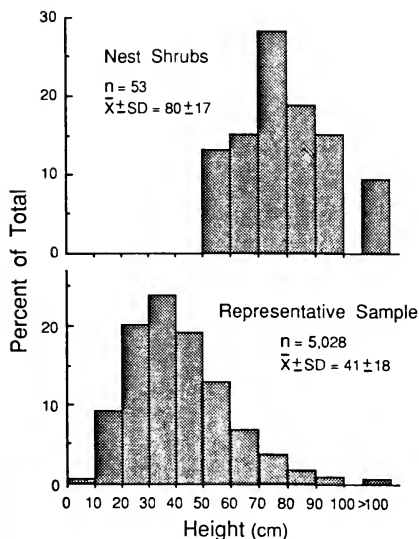
<sup>a</sup>Sample size.<sup>b</sup>Nesting microhabitat differs from study area in general ( $p < .05$ ,  $t$  test).<sup>c</sup>Coefficient of variation of intershrub distances.

Fig. 1. Frequency distributions of heights of Sage Thrasher nest shrubs and a representative sample of sagebrush shrubs from the study area in general.

(Fig. 1). Shrubs less than 50 cm tall constituted 73% of all available shrubs; yet no shrubs in this size range were used as nest substrates. Indeed, 72% of the nests found were in or under shrubs greater than 70 cm tall; shrubs in this size range composed only 7% of all available shrubs.

Shrubs used for nesting by Sage Thrashers differed from available shrubs in several other respects. Nearly all shrubs used by thrashers were 75% or 100% living (Table 2). This differed markedly from the distribution of available shrubs among the condition classes, in which many shrubs were less than 75% living.

Further, most available shrubs bearing foliage had intermediate foliage density. Although two-thirds of the nest shrubs also had intermediate foliage density, shrubs with high foliage density were used disproportionately by thrashers as nest substrates, and shrubs with low foliage density were used little. The canopy continuity of shrubs evidently did not influence shrub selection by thrashers; the frequencies with which gaps occurred in the canopies of nest shrubs and available shrubs were nearly identical. Finally, a significantly greater than expected proportion of shrubs used for nesting had branches or foliage within 30 cm of the ground.

#### Nest Placement Within Substrates

Thrashers placed their nests deep within or beneath shrubs (Table 3). Nest height averaged only slightly more than a third of the substrate height. Further, nests were placed horizontally relatively far from the perimeter and close to the center of the shrub. Several of these measurements are noteworthy because of their relative constancy; coefficients of variation were small for relative nest height and distances from the nest to the perimeter and the top of the shrub.

The overall pattern of Sage Thrasher nest orientations (Fig. 2) was not significantly different from a uniform distribution ( $X^2 = 9.6$ , 7 df,  $p = .22$ ), but easterly (NE, E, SE) exposures were more prevalent than westerly (NW, W, SW) exposures. A comparison of all easterly orientations (combined) to all westerly orientations was significant ( $X^2 = 6.1$ , 1 df,  $p = .02$ ).

#### DISCUSSION

Sage Thrashers were selective in their choice of nest sites. In microhabitats chosen

TABLE 2. Comparisons of Sage Thrasher nest shrubs with a representative sample of sagebrush shrubs from the study area in general. Values represent frequencies of occurrence and percentages (in parentheses) of the total.

Variable	Nest shrubs	Representative sample	$\chi^2$	<i>p</i>
Condition			27.15	< .01
Dead	1 (2)	1109 (22)		
25% living	0	312 (6)		
50% living	2 (4)	617 (12)		
75% living	13 (24)	709 (14)		
100% living	37 (70)	2269 (45)		
Foliage density			5.87	.05
Low	3 (6)	515 (13)		
Intermediate	35 (67)	2762 (71)		
High	14 (27)	632 (16)		
Canopy continuity			0.01	.99
With gaps	22 (42)	2041 (41)		
Without gaps	31 (58)	2959 (59)		
Profile			4.91	.03
Full <sup>a</sup>	49 (92)	1875 (80)		
Not full	4 (8)	461 (20)		

<sup>a</sup>Branches or foliage within 30 cm of the ground.

TABLE 3. Aspects of nest placement by Sage Thrashers.

Variable <sup>a</sup>	$\bar{x}$	SD	CV
Nest height (cm)	30	13	43
Relative nest height (%)	37	12	33
Horizontal distance to perimeter (cm)	33	8	25
Horizontal distance to center (cm)	17	10	63
Distance to top (cm)	47	11	24

<sup>a</sup>*n* = 53 for all variables.

for nesting, the coverage of sagebrush seemingly was not important, but the size and spatial distribution of the shrubs were. And thrashers seemed to select areas in which total vegetation coverage was sufficient to lessen the amount of bare ground. Other studies also have documented nonrandom use of microhabitat for nest sites (e.g., MacKenzie and Sealy 1981, Petersen and Best 1985). Further, shrubs selected as nest substrates differed from the sample of shrubs representative of the study area in nearly every character that we measured.

Ultimate causes of nest-site selection patterns of Sage Thrashers are unknown, but two likely selective agents are predation pressure and microclimate. For example, Sage Thrashers may place their nests in large shrubs because their nests are large and bulky (personal observation) and would be less conspicuous in large than in small shrubs. Placement of nests in living shrubs, in shrubs with high foliage

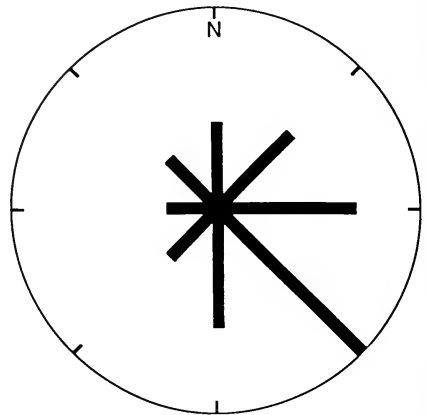


Fig. 2. Distribution of Sage Thrasher nest orientations (*n* = 53) relative to the center of the support or overhead (for ground nests) shrub. The length of each bar is proportionate to the number of nests having that orientation.

density, and in shrubs with branches and foliage within 30 cm of the ground could be influenced by the need for concealment or cover from predators or weather. Nest concealment in birds is related in part to probability of predation or amelioration of microclimate (e.g., Pleszczyńska 1978, Wray and Whitmore 1979, Murphy 1983, Martin and Roper 1988). The potential importance of nest



obscurement and cover for thrashers is suggested also by observations of platforms of twigs in shrub canopies above some nests (Rich 1980, 1985; personal observation). Rich (1980) believed that some such canopies were old nests, but none that we observed appeared so. In one instance that we observed, twigs were placed in the shrub canopy about one week after the nest was initiated.

Aspects of nest placement within substrates (e.g., nest height, nest orientation) also have been found to be related to nesting success (e.g., Murphy 1983, Westmoreland and Best 1985) and microclimate amelioration (Horvath 1964, Rich 1978). In particular, nonrandom nest orientation typically is thought to reflect responses by birds to prevailing winds or the radiative environment (e.g., Austin 1976, Petersen and Best 1985, Ferguson and Siegfried 1989). Favoring easterly and avoiding westerly exposures for nests may reflect attempts by thrashers to maximize exposure to the morning sun, shading from the afternoon sun, or both.

It is possible, of course, that factors other than predators or microclimate accounted for the patterns we observed. For example, selection of a large shrub for nesting may denote the need for structural support for the nest. The tendency of Sage Thrashers to select microhabitats with large, clumped shrubs might simply reflect the spatial distribution of areas conducive to robust sagebrush growth. Thus, selection of a large shrub for nesting could, de facto, place the nest in an area of large, clumped sagebrush. Or, because thrashers forage primarily on the ground (personal observation), clumped shrubs perhaps provide a favorable interspersed of shrubs and openings for foraging near the nest.

Although the determinants of nest-site selection by Sage Thrashers are not known for certain, several lines of evidence suggest that thrasher nest-site selection is strongly stereotypic. First, the use of sagebrush plants as nest substrates is ubiquitous. Reynolds and Rich (1978), Rich (1978, 1980), and Reynolds (1981) also found nests only in or under big sagebrush plants. Castrale (1982) found one thrasher nest in a juniper (*Juniperus osteosperma*) tree. To our knowledge, this is the only documented instance of a Sage Thrasher nest in anything but sagebrush. Second, Sage Thrashers are specific in that their nest sites

differ in many respects from the average available habitat. Third, variation in the height of shrubs chosen (coefficient of variation = 21%, compared to 44% for the representative sample of shrubs from the study area) and in several of the nest placement variables is small (Table 3). Moreover, the mean nest shrub height is similar to means reported in other studies (Reynolds and Rich 1978, Rich 1980, Reynolds 1981, Castrale 1982). Sage Thrashers are characteristic of most sagebrush-dominated rangelands in the United States (Wiens and Rotenberry 1981), and because thrashers have evolved in sagebrush habitat, the specificity of their nest-site selection should not be surprising. The patterns that we observed likely have been molded by a long history of exposure to a particular suite of selective agents.

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## FISHES OF BLY TUNNEL, LASSEN COUNTY, CALIFORNIA

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**ABSTRACT.**—Leon Bly Tunnel, which connects Eagle Lake to Willow Creek, was investigated to see if the water issuing from the tunnel was lake water or spring water and to check reports of its being inhabited by fish. We found that the water was similar to that of highly alkaline Eagle Lake, despite a block placed in the tunnel in 1986. Five species of fish were found in the tunnel, the same species inhabiting both Willow Creek and Eagle Lake, although the creek was much warmer and less alkaline than the lake. The fish originated from the creek. Fish in the tunnel were either not feeding or were consuming snails (*Vorticifex* sp.), the principal invertebrate present. The largest fish (35 cm SL) captured were rainbow trout (*Oncorhynchus mykiss*).

**Key words:** *Eagle Lake, rainbow trout, Lahontan reddsides, fish.*

Leon Bly Tunnel was constructed in 1923 to deliver water from Eagle Lake, a large natural lake on the western edge of the Great Basin, Lassen County, California (lat. 40° 37', long. 120° 45'), to the Honey Lake Valley for irrigation. The tunnel is about 2 km long and was cut through old lava flows. The water flows from the tunnel into a ditch that joins Willow Creek, a spring-fed stream. The tunnel was abandoned as a source of irrigation water shortly after it was built (1936) because falling lake levels reduced its ability to deliver water and a landslide partially blocked the tunnel entrance (Amesbury 1971, Purdy 1988). However, water continued to flow from the tunnel, and in November 1986 the Bureau of Land Management installed a concrete plug in the tunnel in an attempt to raise the lake level (Purdy 1988). In June and July 1990 we investigated the tunnel to see (1) if the water issuing from it was lake or spring water and (2) if there were fish in it. The latter aspect was investigated because of local tales that the tunnel was full of "blind cave fish."

### STUDY AREA

Eagle Lake is a large (ca 12,500 ha) terminal lake that is alkaline (pH 8.5–9.1) and very productive (Huntsinger and Maslin 1976). It contains the only population of rainbow trout (*Oncorhynchus mykiss aquilarum*) native to the Great Basin (Busak et al. 1980), as well as tui chub (*Gila bicolor*), speckled

dace (*Rhinichthys osculus*), Lahontan reddsides (*Richardsonius egregius*), and Tahoe sucker (*Catostomus tahoensis*). Bly Tunnel begins at the lake on the eastern shore of the southernmost of the lake's three basins but can only be entered at its mouth. A steep shaft about halfway along its length was used during the 1923 excavation and is currently barred by a locked gate. The tunnel itself is 2.1 m high and 2 m wide at the base, with walls that are about half bare rock, half concrete. The water in the tunnel is 40–50 cm deep and forms riffles and pools in places where rock has fallen into the tunnel or sand and debris have accumulated on the bottom. After leaving the tunnel, the water flows 600 m through a long, shallow ditch (average depth about 30 cm) that has little cover for fish. The ditch empties into Willow Creek, which has its origins about 1 km upstream in a series of seeps and springs that coalesce in a large, wet meadow. Willow Creek, tributary to the Susan River, contains the same fish species as Eagle Lake, with the addition of Paiute sculpin (*Cottus beldingi*), although rainbow trout are very scarce and found primarily in the 1 km of stream below the mouth of the ditch. These trout probably originated from fish planted in the stream at some earlier time.

### METHODS

Total alkalinity and hardness (both as mg CaCO<sub>3</sub> per L) were measured using Bausch

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TABLE 1. Some characteristics of the water of Eagle Lake, Bly Tunnel, and Willow Creek, June 1990.

	Conductivity	Alkalinity <sup>a</sup>	Hardness <sup>a</sup>	Temperature (C)	Flow (m <sup>3</sup> /min.)	Time	Date
Eagle Lake	910	440	280	18 <sup>b</sup>	—	1015	6/29
Bly Tunnel	860	410	260	11	4.4	1530	6/19
Headwater springs	180	60	80	21	2.0	1430	6/19
Willow Creek <sup>c</sup>	350	350	200	21 <sup>d</sup>	7.7 <sup>e</sup>	1430	6/23

<sup>a</sup>Mg CaCO<sub>3</sub>/L.<sup>b</sup>Surface temperature, coldest temperature (at 14 m) was 14 C.<sup>c</sup>Just below convergence with ditch from tunnel.<sup>d</sup>The spring flows warmed to 25 C and the tunnel water to 18 C by the time they converged.<sup>e</sup>Other springs contribute to flow as well as headwater springs.

and Lomb Spectrokits (titration). Conductivity was measured using a Hach portable conductivity meter. Water velocities were determined using a Marsh-McBirney Model 201 electronic flow meter. Flows (m<sup>3</sup>/min) were approximated at each locality by measuring depths and mean water column velocities at 10 evenly spaced places on a transect across the stream and then multiplying width by mean water column velocity (m/sec) by mean depth by 60. Fishes in Willow Creek were collected with a Smith-Root Type XI electrofisher at numerous localities during 17 June–15 July 1990 as part of a detailed study of the creek's fish fauna. The tunnel fauna was sampled on 4 July 1990 between 1300 and 1500 hr. Only the first 600 m of tunnel was investigated, and at the farthest point the light from the end of the tunnel was still faintly visible. The conductivity of the tunnel water was too high for electrofishing, so fish were collected with dipnets. This proved easy to do, as they were confused by the light from our flashlights. Samples of fish from the creek and the tunnel were killed and then preserved in a 4% formaldehyde solution for dietary analysis. Diets were determined by identifying the stomach contents and estimating relative volumes of each item using the points method of Hynes (1950). Most fish were discarded after use, but voucher specimens are in the University of California, Davis, fish collection. Tunnel invertebrates were sampled with a kick screen.

## RESULTS

The chemistry of the water issuing from the tunnel had a high conductivity, hardness, and total alkalinity (Table 1). All values were only slightly lower than those of Eagle Lake and

much higher than those of spring water feeding Willow Creek. Temperature of the tunnel water was 11 C, colder than either the stream or lake (Table 1). At the point it flowed into the creek it had warmed to 18 C (late afternoon). The outflow of the tunnel contributed more than half the flow of Willow Creek, raising its alkalinity, hardness, and conductivity. The tunnel water also caused lower temperatures in the creek in a reach ca 500 m below the ditch entrance. However, because the stream is wide, shallow, and without riparian vegetation (due to heavy grazing), the water temperatures below this reach were typically 23–24 C by late afternoon in late June and early July.

Fish were common in the tunnel and were first noticed approximately 20 m up from the entrance. In order of abundance, the fishes collected were Lahontan redbreast (25), Tahoe sucker (6), speckled dace (5), rainbow trout (2), and tui chub (1), although speckled dace and Tahoe sucker may have been under-sampled because of their tendency to hide in bottom debris or in crannies along the side of the tunnel. In Willow Creek the fishes present, in order of numerical abundance, were speckled dace, Lahontan redbreast, Tahoe sucker, tui chub, Paiute sculpin, and rainbow trout. The size classes of fish encountered in the tunnel were similar to those found in the stream, except that young-of-year fish (<30 mm SL) seemed to be absent and the two rainbow trout captured were larger than any taken from the stream. The largest trout, which was captured and released, was a hook-jawed male in spawning colors 350 mm SL. The other trout was a 184-mm-SL male. The largest fish other than trout were two 140–150-mm-SL suckers that were also captured and released. All fishes captured were similar in coloration to fish in the stream, and the

TABLE 2. Percentages of items in diets of fishes from Willow Creek and Bly Tunnel, Lassen County, California, in July 1990. A more detailed taxonomic breakdown of the gut contents is available from the senior author.

	N	SL (mm)	No. empty stomachs	Odo- nata	Ephem- eroptera	Tri- choptera	Coleoptera	Hemiptera	Diptera	Gastro- poda	Misc invertebrates	Algae/ detritus
Lahontan reidside												
Tunnel	16	75	10	—	—	—	—	6	7	86	1	—
Creek	50	59	15	—	12	18	4	5	4	9	16	32
Speckled dace												
Tunnel	5	41	5	—	—	—	—	—	—	—	—	—
Creek	55	38	39	8	71	7	—	6	2	3	—	3
Tui chub												
Tunnel	1	60	1	—	—	—	—	—	—	—	—	—
Creek <sup>a</sup>	18	57	1	10	56	—	2	2	—	10	15	5
Tahoe sucker												
Tunnel	4	99	3	—	—	—	—	—	—	5	—	95
Creek <sup>a</sup>	24	70	2	12	26	12	2	—	30	2	12	2
Rainbow trout												
Tunnel	1	184	0	—	—	—	—	—	—	100	—	—
Paiute sculpin												
Creek	21	51	8	59	6	9	—	—	6	2	17	—

<sup>a</sup>Excludes unidentifiable material which made up >70% of gut contents.

larger reidsides had traces of red on their sides (as did the creek fishes), remnants of spawning colors (Moyle 1976). All fish appeared healthy and showed no signs of starvation. The only fish observed in the ditch between the creek and the tunnel were a few small speckled dace, which we were unable to capture. Two standard minnow traps set overnight at the mouth of the tunnel failed to catch any fish, although such sets are generally successful in Willow Creek.

The guts of fishes collected from the tunnel were either empty or full of *Vorticifex* (*Paraphlox*) sp., a snail that was the principal aquatic invertebrate collected in the tunnel and which literally coated the bottom in places. Two reidsides, however, also contained some adult insects (Table 2). Snails were relatively uncommon in the diets of Willow Creek fish, which fed primarily on aquatic insects. The only aquatic invertebrates besides snails collected in the tunnel were large annelid worms.

## DISCUSSION

The highly alkaline water flowing through Bly Tunnel clearly has its source in Eagle Lake. Presumably, underground passage cools the water to 11 C. The fish, however, most likely moved up from Willow Creek, as they are roughly in the same relative abun-

dances in the tunnel as in the creek, except for the absence of sculpins. Further evidence of this is that the rainbow trout captured were clearly wild fish (although not native to the drainage), with the fin conformations associated with wild fish. Trout in the lake are all the result of planting, and most have deformed fins from their hatchery rearing; in addition, they are planted at sizes larger (25–30 cm) than most trout in the tunnel and creek. Scales from the 184-mm trout indicated that it was 2+ years old, a fairly typical size for a stream rainbow trout (Moyle 1976). The ages and growth patterns of Lahontan reidsides from the tunnel, as revealed by examination of scales, did not seem to differ from those of stream fish.

It seems likely that the fish are recent invaders of the tunnel. Presumably, they moved up earlier in the year when the water in Willow Creek was cooler and there was less of a temperature gradient. The clear water of the outflow ditch provides little shelter from bird predation, so fish are likely to persist in this area only if they move into the tunnel. We have observed Common Mergansers in the ditch, and our studies of Willow Creek indicate that predation by several species of birds is a major factor limiting fish populations (unpublished data). Although we failed to catch any fish in minnow traps set near the tunnel mouth, the presence of adult insects in

two redside stomachs indicates either that individuals occasionally may venture out to feed or that individuals are continually arriving despite the temperature gradient and their vulnerability to predators in the ditch. Speckled dace may venture out to feed at night, the time they are most active in the creek, but the other fishes are more active during the day (unpublished data). The healthy appearance of all fish indicates they are not starving under tunnel conditions.

This study also shows that the attempts to block Bly Tunnel to keep it from draining Eagle Lake have been at best only partially successful. The comparatively low flows now coming out of the tunnel may simply be the result of low lake levels following a long series of dry years. If the lake level rises again, outflow of the tunnel should be monitored and further attempts made to block the outflow if it is found to be keeping the lake at an artificially low level.

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## HEAVY METAL TOLERANCE OF INLAND SALTGRASS (*DISTICHLIS SPICATA*)

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**ABSTRACT.**—Inland saltgrass (*Distichlis spicata*) occurs on at least two metal-contaminated sites in southwestern Montana. As a result of mining, milling, and smelting activities, soils have elevated concentrations of copper, zinc, and manganese. One soil is acidic (upper horizons), slightly saline, and moderately sodic. The other soil is alkaline, nonsaline, and nonsodic. The fact that inland saltgrass grows on these soils and does not accumulate dangerous levels of metals makes it a candidate species for revegetating hardrock mining and other metal-polluted sites.

**Key words:** inland saltgrass, *Distichlis spicata*, preadaptation, metal-contaminated soils.

*Distichlis spicata* (L.) Green var. *stricta* (Torr.) Beetle, commonly known as inland saltgrass, is a perennial, shallow-rooted, warm-season grass that grows from hard, scaly rhizomes. Palatability is low but is enhanced by heavy cropping, which also promotes a dense sod (Weaver 1954).

*D. spicata* is most commonly found on moist saline soils in the Great Plains. Daubenmire (1974) referred to inland saltgrass as an example of plant zonation around a saline basin; saltgrass was found in the wettest and saltiest sites occupied by vascular plants. Elsewhere, other species may exhibit greater salt tolerance (Dodd et al. 1964, Unger 1974). The soil salt content associated with saltgrass communities can range at least from 0.03 to 5.6% (Unger 1974). Inland saltgrass can tolerate an average soil electrical conductivity (EC) of 66 mmhos/cm in the upper 10 cm of soil (Unger 1969). However, in mixed-prairie communities where saltgrass is abundant in east central Montana, saltgrass occur on soils with ECs of  $\leq 2$  (Proddgers 1978). Saltgrass abundance appears to increase in response to grazing intensity in mixed communities adjacent to more saline sites.

The relative abundance of cations and anions in soils of saltgrass communities varies with soil horizon and site. The predominant cation is usually sodium, but magnesium, potassium, or calcium may be abundant (Dodd et al. 1964, Dodd and Coupland 1966a, Ludwig and McGinnies 1978). Principal anions are sulfate, bicarbonate, and chloride.

Proddgers (1978) reported sodium adsorption ratios (SARs)  $>60$  for saltgrass community soils. Ludwig and McGinnies (1978) reported an SAR of 4 in the A horizon and 79 in the C horizon. Soil pHs for inland saltgrass communities commonly range from 7 to 10 (Poole 1980).

The ability of saltgrass to grow on salty sites may depend on its ability to exclude salts. *Distichlis spicata* can survive salt-stressed environments by a process in which vacuolar compartmentation of salt is followed by osmotic compartmentation in the cytoplasm via an organic solute such as proline (Daines and Gould 1985). Inland saltgrass maintains high osmotic pressure in the cell sap. Dodd and Coupland (1966b) measured osmotic pressures in *D. spicata* of 22–48 atmospheres in a saline meadow community. This suggests that the membranes of saltgrass can extract water from the matrix of saline soils. Efficient membranes might also exclude salts and metals from critical sites in the plant. *Distichlis* has been reported to secrete salts, allowing it to survive what would otherwise be excessive ionic accumulation (Frey-Wyssling 1935, as cited in Unger 1974).

We speculate that salt-excluding mechanisms may preadapt saltgrass to grow on metal-rich sites and suggest that, if so, saltgrass might be planted on metal-contaminated sites to provide cover. Due to the rhizomatous growth form, saltgrass spreads vegetatively and controls soil erosion. Low

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Fig. 1. Inland saltgrass community on streambank tailings near Ramsay, Montana. Floods deposited tailings and mining detritus along stream. Contagious distribution of vegetatively spreading saltgrass community is evident.

palatability is desirable for revegetation of metal-contaminated sites.

To determine the metal tolerance and metal-excluding capabilities of saltgrass, we measured the metal concentrations of saltgrass tissues and associated soils at two contaminated sites. Comparison is made between acceptable metal levels in livestock forage and normal metal concentrations in soils.

#### SITES AND METHODS

Two *Distichlis spicata* communities were investigated on metal-rich soils in southwestern Montana. One community is situated on stream-deposited hardrock mine tailings along Silver Bow Creek near Ramsay, Montana, Section 22, T3N, R9W, at an elevation of 1615 m (Fig. 1). The tailings originated at upstream milling and smelting operations along the creek from 1860 to 1910. A series of floods in the 1890s and a major flood in 1908 washed tailings into the creek. Subsequent floods since 1908 (particularly in 1948, 1975, 1980, and 1981) have re-deposited tailings

along the creek (CH2M Hill 1989). These tailings deposits now occur along the creek in distinctively colored strata, most of which are rich in heavy metals and low in pH due to pyrite oxidation. Some taller plants, such as willows, have survived tailings deposits, but shorter vegetation was buried and current grass and forb plant communities represent colonization by adapted species.

The second community occurs on an upland Mollisol derived from frost-worked travertine a few hundred meters from the copper smelter stack near Anaconda, Montana, in Section 12, T4N, R11W, at an elevation of 1740 m (Fig. 2). This site has received heavy metal deposits and sulfur dioxide fumigation from the smelter stack dating roughly from 1900 to 1980. Vegetation within several miles of the stack has been dramatically affected by stack emissions. Erosion from a nearby road has resulted in soil deposition in the *Distichlis spicata* community. Inland saltgrass does not typically occur on upland Mollisols.

Three soil pits were located to encompass surficial variability within each community.





Fig. 2. Inland saltgrass-Great Basin wildrye plant community near copper smelter at Anaconda, Montana. Although Great Basin wildrye is more conspicuous in the photo due to its height, saltgrass has greater canopy coverage. Heavy metals in soils were deposited as airborne fallout from the copper smelter (background) and through deposition of erosional sediments.

Soil profiles were described and .5 kg of soil was collected from each horizon at each pit. Particle size was determined following the procedure of Day (1965). Electrical conductivity, SAR, and pH were determined from

saturated paste extracts. Soils were digested in 4M  $\text{HNO}_3$  at 70 C overnight (Chang et al. 1987) for total analysis of copper, manganese, and zinc. Extractable metal concentrations were determined using DTPA (Lindsay and

TABLE 1. Profile description for streambank mine tailings soil near Ramsay, Montana.

Horizon	Depth (cm)	Texture	Structure	Consistency	Roots	pH <sup>a</sup>	EC <sup>a</sup> (mmhos/cm)	SAR <sup>a</sup>
A	0-13	very fine sandy loam	massive	slightly hard very friable nonsticky, nonplastic	none (underground culms)	4.0-4.9	4-8	1-4
C1	13-20	fine and very fine sandy loam	massive	soft very friable nonsticky, nonplastic	culms, rhizomes, very few medium, fine, and very fine roots	5.4-7.6	4-8	2-5
C2	20-33	very fine sandy loam	massive	hard very friable nonsticky, nonplastic	common medium, few fine and very fine roots	5.4-7.6	4-8	2-5
Ab	33-46	very fine sandy loam	massive	slightly hard friable slightly sticky, slightly plastic	few rhizomes, few fine and very fine roots	6.5-7.6	2-10	2-9
C1b	46-74	silt loam	massive	soft friable slightly sticky, slightly plastic	few fine and very fine roots	7.8-7.9	1-7	2-13
C2b	74-100	silt loam	massive	slightly hard friable slightly sticky, slightly plastic	few fine and very fine roots	7.8-7.9	1-7	2-13
2Cb	100-127	very fine sandy loam	massive	soft friable nonsticky, nonplastic	very few fine and very fine roots	7.5-8.0	1-3	3-18

<sup>a</sup>Ranges based on three field subsamples of each horizon.

Norvell 1969, Soltanpour et al. 1976) in the absence of triethanolamine. Copper, zinc, and manganese concentrations in digestates and DTPA extracts were analyzed using inductively coupled plasma emission spectroscopy (ICP).

Soil profile descriptions are summarized in Tables 1 and 2. At the streambank tailings site, near-surface horizons are acidic, but pH increases in the deeper, poorly aerated horizons. These tailings generate acid in an oxidized environment. This soil is slightly saline, but sodium is not excessive, although borderline in some horizons. At the smelter site, where the soil parent material is frost-worked travertine, pH is slightly alkaline, the soil is nonsaline, and due to the predominance of calcium, SARs are <1.

Plant communities were sampled by esti-

mating canopy coverage (Daubenmire 1959) in 20 × 50-cm quadrats placed at 1-m intervals (smelter) or 3-m intervals (tailings) along linear transects. Due to the shapes of the plant communities, the tailings *D. spicata* community was sampled along a single 75-m transect ( $n = 25$ ), whereas the smelter community was sampled along three transects with total length of 40 m ( $n = 40$ ). The larger sample size was appropriate for the more heterogeneous community at the smelter site. Aboveground plant tissue samples were clipped above 3 cm at random intervals along transects, separated into foliage and inflorescences, oven-dried at 70 °C, chopped, digested in nitric-perchloric acid, and analyzed with ICP (Haylin and Soltanpour 1980). Inflorescences make up a small portion of saltgrass production in most years.

TABLE 2. Profile description for soil near copper smelter at Anaconda, Montana.

Horizon	Depth (cm)	Texture	Structure	Consistency	Roots	pH <sup>a</sup>	EC <sup>a</sup> (mmhos/cm)	SAR <sup>a</sup>
A	0-8	very fine sandy loam	massive	soft very friable slightly sticky, slightly plastic	few stems, rhizomes	7.4-8.0	0.6-0.8	0.2
Ab	8-25	gravelly very fine sandy loam	moderate medium angular blocky	soft very friable slightly sticky, slightly plastic	few fine and very fine roots	7.2-7.8	0.3-1.1	0.1-0.2
Bw	24-25+	gravelly very fine sandy loam	massive	soft very friable nonsticky, nonplastic	common fine and very fine roots	7.5-8.1	0.4-0.9	0.2

<sup>a</sup>Ranges based on three field subsamples of each horizonTABLE 3. Species composition of two *Distichlis spicata* var. *stricta* communities.

Species	Streambank tailings site		Copper smelter site	
	Canopy coverage	Frequency	Canopy coverage	Frequency
<i>Agrostis</i> sp.	NP <sup>a</sup>		0.1	2
<i>Distichlis spicata</i>	32.6	92	32.8	95
<i>Elymus cinereus</i>	NP		17.0	60
<i>Juncus balticus</i>	1.0	4	NP	
<i>Muhlenbergia asperifolia</i>	NP		0.1	2
<i>Tetradymia canescens</i>	NP		1.9	5
Litter	39.7	100	45.3	100
Bare soil	49.3	100	21.6	95
Surficial rock fragments <sup>b</sup>	NP		3.8	52

<sup>a</sup>NP = not present.<sup>b</sup>>2 mm.

Plant community compositions are summarized in Table 3. *Distichlis spicata* is the sole dominant species in the community located on the streambank tailings. At the smelter site, the much taller *Elymus cinereus* is subdominant in coverage, and several other species are present. *Elymus cinereus*, *Muhlenbergia asperifolia*, and *Tetradymia canescens* are more abundant at other sites near the smelter than is *D. spicata*.

## RESULTS AND DISCUSSION

### Metal Concentrations of Soils

Tables 4 and 5 present mean concentrations of Cu, Zn, and Mn by soil depth at each site. Subsample concentrations of metals for each depth increment varied, thus the rather large variance. Three replicates of one soil sample were analyzed concurrently with other total

and extractable metal determinations. The average coefficients of variation for extractable and total metal determinations were 3.0% and 3.4%, respectively, demonstrating good precision for laboratory techniques. Therefore, the high variability in metal concentrations from proximate soil samples appears to be due to variations in alluvial deposits rather than imprecise analysis.

At the smelter site, total and available metal concentrations decrease with depth as expected for pollutants deposited on the surface (Table 4). Root distribution was difficult to quantify due to the presence of 20-35% rock fragments, but roots were scarce below .5 m. Flagstones often terminated root penetration and resulted in concentrations of roots immediately above the flagstones. The A horizon contained mostly stems and some rhizomes, so roots were most abundant in the Ab and Bw horizons (8-45+ cm).

TABLE 4. Heavy metal concentrations in copper smelter soil supporting *Distichlis spicata* (means and standard deviations).

Depth (cm)		Cu	Zn	Mn
		----- $\mu\text{g/g soil}$ -----		
0-8	Total	3600 $\pm$ 980	2600 $\pm$ 520	1200 $\pm$ 130
	DTPA	410 $\pm$ 52	180 $\pm$ 47	2.8 $\pm$ 2.1
8-25	Total	1900 $\pm$ 650	1400 $\pm$ 480	780 $\pm$ 160
	DTPA	320 $\pm$ 150	200 $\pm$ 37	11 $\pm$ 14
25-45+	Total	410 $\pm$ 180	500 $\pm$ 170	570 $\pm$ 69
	DTPA	190 $\pm$ 110	200 $\pm$ 50	13 $\pm$ 17

TABLE 5. Heavy metal concentrations in alluvial tailings soil supporting *Distichlis spicata* (means and standard deviations).

Depth (cm)		Cu	Zn	Mn
		----- $\mu\text{g/g soil}$ -----		
0-13	Total	3700 $\pm$ 1200	1700 $\pm$ 480	1700 $\pm$ 510
	DTPA	800 $\pm$ 220	240 $\pm$ 72	170 $\pm$ 76
13-33	Total	13,000 $\pm$ 3600	5700 $\pm$ 1700	5300 $\pm$ 1200
	DTPA	690 $\pm$ 190	130 $\pm$ 80	68 $\pm$ 42
33-46	Total	9200 $\pm$ 7300	6200 $\pm$ 4800	4900 $\pm$ 6400
	DTPA	440 $\pm$ 290	86 $\pm$ 50	41 $\pm$ 35
46-100	Total	340 $\pm$ 250	410 $\pm$ 420	710 $\pm$ 380
	DTPA	43 $\pm$ 30	26 $\pm$ 27	31 $\pm$ 13
100-127	Total	120 $\pm$ 73	67 $\pm$ 40	310 $\pm$ 200
	DTPA	15 $\pm$ 30	3.9 $\pm$ 2.5	11 $\pm$ 6.1

At the streambank tailings site, the depositional sequence of varied tailings materials and subsequent migration of soluble metals have resulted in the highest metal concentrations in the zone where roots are most abundant (13-46 cm depth). Metal concentrations were lower in the surface horizon (0-13 cm) where underground stems and rhizomes were well represented but few roots occurred. Metal concentrations were lowest in the 46-127-cm-depth interval, where roots were less common than higher in the profile.

Total Cu concentrations in the upper 46 cm at the streambank tailings site and upper 8 cm at the smelter site were 100 or more times higher than "normal" soils. Total Cu concentrations in soils summarized by Adriano (1986) averaged 30  $\mu\text{g Cu/g soil}$ , ranging from 2 to 250  $\mu\text{g Cu/g soil}$ . Total Cu concentrations in samples of soils in Japan ranged from 4 to 176  $\mu\text{g Cu/g soil}$  (Iimura 1981). In Japan the legal limit of Cu in agricultural soils is 125 ppm (based on 0.1 N HCl extraction), as stipulated in the Agricultural Land Soil Pollution Prevention Law (Chino 1981).

Total Zn concentrations in the upper horizons of the studied saltgrass soils were roughly 15 to 70 times higher than average. Adriano (1986) reported total Zn concentrations ranging from 1 to 900  $\mu\text{g Zn/g soil}$ ; the average was 90  $\mu\text{g Zn/g soil}$ . Soil samples from Japan contained 10 to 662  $\mu\text{g Zn/g soil}$  (Iimura 1981).

Total Mn concentrations reported in Tables 4 and 5 range from normal to about 10 times higher than usual. Total Mn concentration in soils reported by Shacklette et al. (1971) averaged 560  $\mu\text{g Mn/g soil}$ , with values ranging from 1 to 7,000  $\mu\text{g Mn/g soil}$ . In another summary, the mean total Mn content of surface soils ranged from 80 to 1,315  $\mu\text{g Mn/g soil}$  (Kabata-Pendias and Pendias 1984).

In a different study conducted near East Helena, Montana, soils were sampled and mapped on the basis of metal contamination from a smelter located in East Helena, which is about 89 km northeast of the study sites reported here. Soils that presumably were unaffected by smelter pollution had geometric mean DTPA-extractable concentrations in the upper 38 cm of soil of approximately

TABLE 6.—Heavy metal concentrations in foliage of *Distichlis spicata* and *Elymus cinereus* grown on soils described in Tables 1, 2, 4, and 5.

Site	Species	Cu	Zn	Mn
		----- $\mu\text{g/g tissue}$ -----		
Tailings	<i>D. spicata</i>			
	Inflorescence	490	490	430
	Foliage	130	230	150
Smelter	<i>D. spicata</i>			
	Inflorescence	260	190	45
	Foliage	94	120	25
	<i>E. cinereus</i>			
	Foliage	87	91	39

1 mg/kg Cu, 15 mg/kg Mn, and  $<0.1$  mg/kg Zn (CH2M Hill 1987). The soils reported here contain far more Cu and Zn than these background concentrations.

In summary, comparisons of our data with those reported in the literature demonstrate that the upper .5 m of soil at the streambank tailings site had very high concentrations of all three metals. The smelter soil had very high Cu and Zn concentrations, but not Mn.

#### Metal Concentrations of Foliage

Foliar metal concentrations of *Distichlis spicata* and *Elymus cinereus* were similar; however, *D. spicata* inflorescences accumulated higher metal concentrations, particularly Cu, than did foliage (Table 6).

Plant shoots usually do not accumulate more than 200  $\mu\text{g Cu/g}$  foliage (dry weight), a concentration often considered the threshold value above which plant injury may occur (Kabata-Pendias and Pendias 1984). Maximum tolerable levels of Cu in forage (total diet) for cattle, sheep, and horses are 100, 25, and 800  $\mu\text{g/g}$  of forage, respectively (NAS 1980). These values are based on residues in human food as well as animal health. Foliar concentrations reported in Table 6 are unacceptable for sheep, marginal for cattle, and acceptable for horses, since horses are not generally considered a meat source in the United States.

The maximum tolerable diet concentration of Mn for cattle and sheep is 1000  $\mu\text{g Mn/g}$  forage (NAS 1980). Many plant species are affected by Mn concentrations around 500  $\mu\text{g Mn/g}$  tissue (dry weight), but resistant species or races can tolerate concentrations above 1000  $\mu\text{g/g}$ . The foliar Mn concentration of saltgrass (Table 6) is acceptable for livestock.

Animals are tolerant of high Zn levels in their diet (National Research Council 1979). Maximum tolerable diet concentrations of Zn are 500  $\mu\text{g Zn/g}$  forage for cattle and 300  $\mu\text{g Zn/g}$  forage for sheep (NAS 1980). Cereal grains and vegetables usually contain less than 50  $\mu\text{g Zn/g}$  tissue (Kabata-Pendias and Pendias 1984). While elevated, the foliar Zn concentration of saltgrass is acceptable for livestock grazing.

Considering the very high metal concentrations in the soil, *D. spicata* appears largely to exclude these metals from foliage. Only the Cu concentrations are near or above levels that might pose a problem if humans consumed livestock that grazed solely on foliage grown on heavily contaminated soils from the affected areas. However, livestock ingestion of contaminated soils could greatly increase livestock intake of heavy metals, particularly when a short-grass such as inland saltgrass is grazed. For this reason, livestock grazing of heavily contaminated sites is not recommended. Under open-range grazing conditions, unpalatable species are desirable for revegetation of metal-contaminated sites.

The preadaptation of saltgrass for metal-rich sites, its low palatability, and its soil-binding characteristics make *D. spicata* an attractive grass for revegetation of appropriate sites. Special metal-tolerant varieties could be developed from genotypes present on sites such as those reported here. In current revegetation practices, *D. spicata* is usually propagated from rhizomes due to problems with germination and seedling emergence; however, seeding is much cheaper and more convenient. Stratification and scarification treatments can increase naturally low germination (Cluff et al. 1983). Metal-tolerant races

of inland saltgrass have potential for revegetation of metal-contaminated areas in the West if establishment from seed proves to be practical.

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NOTES ON CRYPTOGAMIC PLANTS OF UTAH:  
RANGE EXTENSIONS AND SPECIES NEW TO THE STATE  
FROM CAPITOL REEF NATIONAL PARK

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*Key words:* cryptogamic plants, Capitol Reef National Park, Utah, Wayne County, Garfield County.

A recent floristic survey of Capitol Reef National Park, situated in Wayne and Garfield counties in south central Utah, has added many species to its flora (Heil 1990), including numerous rare and endangered species. Because of the great diversity in landforms, elevations, and attendant topographic relief, portions of the Waterpocket Fold in the park have been found to harbor a remarkable number of rare species as well as disjuncts from other areas in the state and the western U.S. (Spence 1987). Several of these are bryophytes, which as a group have less well known distributions in the western U.S. than the vascular plants (Spence 1988).

Additional fieldwork during the 1989–90 season has located several species either new to the state or to Wayne County and Capitol Reef National Park. These include the fern *Dryopteris filix-mas*, and the mosses *Abietinella abietina* and *Leskeella nervosa*. A major range extension is also noted for the moss *Isopterygium pulchellum*. Below, each of the new reports is discussed, along with habitat information, associated species, and regional significance.

The park has a semiarid climate, with hot summers and moderately cold winters. At park headquarters in Fruita (1675 m), average annual precipitation is 18.3 cm, with about 30% falling as late-summer (July–August) thunderstorms. The average July maximum temperature is 19.1°C, while the average January minimum is –21.9°C (park service data, 1948–1986).

*Abietinella abietina* (Hedw.) Fleisch.

UTAH: Wayne Co., Capitol Reef National Park, on dry, shaded Kaibab limestone under *Pseudotsuga menziesii*, middle part of Fremont Gorge, with *Symphoricarpos oreophilus* and *S. longiflorus*. Ele. 1800 m. 38°16'N, 111°17'W, T29S R6E Sec. 21, October 6, 1989. Spence 1104 (deposited in park herbarium).

This is the first report of living material of this species for Utah. The closest known locality for *Abietinella abietina* is a population in Dinosaur National Monument, Moffat County, Colorado (Flowers 1973). The park locality is an unusual habitat for the species, as it is in a relatively low-elevation, semiarid canyon. In the Pacific Northwest *Abietinella* is common at montane and subalpine elevations in the drier parts of the Cascade and Coast mountains (Lawton 1971). The species is found occasionally on dry rock over a wide elevational range in Colorado (Weber 1973).

The stand of Douglas-fir under which the moss was found may be relictual, as it is isolated elevationally from the main forest populations in south central Utah, which usually occur above 2100 m. The distribution and nature of this, as well as other isolated Douglas-fir stands on the Colorado Plateau (e.g., Brotherson et al. 1985, Tuhy and MacMahon 1988), suggest that they may be late Pleistocene–early Holocene relicts. The presence of *Abietinella abietina*, a boreal-arctic moss most common at montane to subalpine elevations in the western U.S., supports this. Remarkably, Betancourt (1984) has

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reported rare macrofossil material of *Abietinella* from Allen Canyon and Fishmouth Caves, ca. 140 km to the southeast of Capitol Reef National Park and near the Abajo Mountains, with radiocarbon ages of 3000–11,000 years and 3700 years, respectively. At least in the Allen Canyon Cave sequence, all packrat middens with *Abietinella* macrofossils also contained *Pseudotsuga menziesii* material.

*Isopterygium pulchellum*  
(Hedw.) Jaeg. & Sauerb.

UTAH: Wayne Co., Capitol Reef National Park. On dry, shaded vertical face of Wingate Sandstone, side canyon of Cohab Canyon, near campground. With *Fissidens bryoides* and *Pseudoleskeella tectorum*. Ele. 1750 m, 38°17'N, 111°14'W, T29S R6E Sec. 23, November 2, 1989. Spence 411S. Also on dry Navajo Sandstone in shaded, humid crevice, just south of Blowout Flats, northeast of Golden Throne. With *Dryopteris filix-mas*, *Desmatodon obtusifolius*, *Pohlia nutans*, and *Amblystegium serpens* var. *juratzkanum*. Ele. 2000 m, 38°14'N, 111°11'W, T30S R7E Sec. 4, May 24, 1990. Spence 4135a (both deposited in park herbarium).

*Isopterygium pulchellum* has been reported once before from Utah (Summit County, Uinta Mountains, at an elevation of 2713 m; Flowers 1973). In western North America, it is most common on humid, shaded wood and soil in coniferous forests and is restricted to high-elevation spruce-fir forests in the southern Rocky Mountains (Ireland 1969, Lawton 1971, Weber 1973). The habitat the plants grew in, shaded Navajo and Wingate sandstones in a semiarid climate, is highly unusual for this species. The plants were restricted to the deepest, most heavily shaded recesses of cracks and are probably never exposed to direct sunlight. They appear to survive only because of a combination of shading and funneling of precipitation into the cracks from rock faces above.

*Leskeella nervosa* (Brid.) Loeske

UTAH: Wayne Co., Capitol Reef National Park. On thin, dry, shaded soil on ledge of Navajo Sandstone, amphitheater directly north of Pioneer Register and west of Capitol Gorge Tanks. With *Petrophytum caespitosum* and *Sclaginella nutica*. Ele. 1900 m, 38°16'N, 111°17'W, T30S R7E Sec. 9, October 24, 1989. Spence 4109a (deposited in park herbarium).

In a recent revision of *Pseudoleskeella*, Wilson and Norris (1989) reported *P. sibirica* (Arn.) P. Wilson & Norris (= *Leskeella ner-*

*vosa* var. *sibirica*) from Utah and distinguished it from *P. nervosa* using leaf and asexual reproductive characters. Using their key, I was able to clearly identify the park plants as *P. nervosa*, inasmuch as they possess asexual brood bodies and the leaves on the upright branches have a strong costa extending somewhat obscurely into the acumen. This is the first report of *Leskeella* (*Pseudoleskeella*) *nervosa* for Utah. As it is found in Arizona, California, and Idaho, its presence in Utah is not unexpected. I agree that *Leskeella* and *Pseudoleskeella* are very close (Wilson and Norris 1989); however, I prefer to maintain them as separate genera for now, based on the occurrence of asexual brood bodies in the former but not the latter.

*Dryopteris filix-mas* (L.) Schott

UTAH: Wayne Co., Capitol Reef National Park. In humid crevice in Navajo Sandstone, just south of Blowout Flats northeast of Golden Throne. With *Cymopteris beckii*, *Erigeron maguirei*, *Desmatodon obtusifolius*, *Pohlia nutans*, and *Amblystegium serpens* var. *juratzkanum*. Ele. 2000 m, 38°14'N, 111°11'W, T30S R7E Sec. 4, July 23, 1990. Spence & Mason 4137 (deposited in park herbarium).

New to Wayne County and Capitol Reef National Park, *Dryopteris filix-mas* has been collected in five other localities in Utah, once each in Garfield, Sanpete and Salt Lake counties, and twice in Washington County (Albee et al. 1988). The closest population is the one in Garfield County. The park plants were growing in a narrow, shaded crevice in Navajo Sandstone in an area of high topographic relief in the Waterpocket Fold of the park, just south of a pristine aeolian grassland/*Pinus ponderosa* woodland complex called Blowout Flats. Three rare species, *Erigeron maguirei* (listed endangered), *Gilia caespitosa* (category 1 species), and *Cymopteris beckii* (category 2 species), were also growing in the crevice. *Dryopteris* is a common circum-boreal fern, abundant in the Pacific Northwest and the northern Rocky Mountains. Further south, it is found in scattered localities in the mountains south to New Mexico and Arizona (Cronquist et al. 1972). The habitat of the park population, at middle elevations in semiarid slickrock, is atypical compared with traditional northern habitats.



## DISCUSSION

All species in this report are rare in Utah and Capitol Reef National Park. The mosses are sterile, while *Dryopteris* produces abundant sori. Unusual habitats, rarity, and disjunct distribution patterns suggest that all these species are relicts from a previous period when climates in the region were milder and wetter, probably the late Pleistocene or early Holocene (Betancourt 1984). All are associated with species, including *Pinus ponderosa*, *Symphoricarpos oreophilus*, *Petrophytum caespitosum*, *Arctostaphylos patula*, *Cymopterus heckii*, and *Gilia caespitosa*, which are at or below their typical lower elevational limits in south central Utah (Welsh et al. 1987). For example, small stands of *P. ponderosa* are found as low as 1800 m in the Fold, where they consist almost exclusively of large (>50 cm dbh) and presumably old trees with little or no recruitment occurring (Spence, unpublished data). The trees are isolated by low elevations (1500 m to the west and 1400 m to the east) and semiarid to arid shrublands from the extensive *P. ponderosa* forests on the Henry, Boulder and Thousand Lake mountains. Populations of these species may be stranded relicts from the late Pleistocene, surviving in the Waterpocket Fold only because of its large vertical relief (700 m) and varied topography and substrates. The fern and mosses can be considered rare components of these relict vegetation patches.

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## FACTORS INFLUENCING DISSOLVED OXYGEN CONCENTRATIONS DURING WINTER IN SMALL WYOMING RESERVOIRS

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*Key words:* dissolved oxygen, reservoir, winter, Wyoming.

Fish kills in ice-covered lakes have been described in the upper Midwest and the Great Plains (Nickum 1970, Patriarche and Merna 1970). Fish losses were related to low dissolved oxygen and several associated factors: small, shallow lakes; periods of prolonged or extensive snow and ice cover; lack of surface water inflow into lakes; and high primary productivity (Greenbank 1945, Halsey 1968, Nickum 1970, and Mathias and Barica 1980).

Miller (1989) investigated the geomorphic features that influence winterkill in natural lakes at elevations >2925 m in the Medicine Bow Mountains, Wyoming. He separated lakes prone to winterkill from those without a history of winterkill on the basis of six discriminating variables: basin area, basin relief ratio, lake area, drainage density, lake volume, and maximum water depth. Winterkill lakes tended to be small, shallow lakes and were at lower elevations than nonwinterkill lakes.

We assessed the winter dissolved oxygen concentrations in small reservoirs (<100 hectares at full pool) at elevations >2100 m above mean sea level. Physical, chemical, and climatic characteristics that are related to low dissolved oxygen under the ice were identified.

### METHODS

Eleven reservoirs were studied during winter, 7 in 1987 and 10 in 1988 (Table 1). Six of the 1988 sites were also sampled the previous year. Study sites were selected to represent a range in elevation, size, and productiv-

ity. The reservoirs were located near or within the Laramie and Medicine Bow mountains in southeastern Wyoming. Several reservoirs had known histories of winterkill.

Bathymetric maps were obtained from the Wyoming State Engineer's Office or constructed from soundings that were plotted on reservoir outlines from U.S. Geological Service topographic maps. The maps were used to calculate morphometric variables: maximum water depth, mean water depth, water volume, and volume of unfrozen water during winter. Water levels were monitored to estimate the minimum values of the morphometric variables during winter.

Macrophyte abundance was estimated in fall 1987 for the 10 reservoirs to be studied. A 10-m line attached to a float was thrown from the shore at 10-m intervals around the reservoir. The density of plants along the line was visually estimated on a scale of 0 to 10. The presence or absence of plants beyond the line was noted and rated (0 = absent, 5 = present). Also, a reservoir-wide rating of filamentous algae was made (0 = absent, 3 = present, 5 = pervasive). The averages for the line and beyond-line ratings were summed with the rating for algae to yield Macrophyte Abundance Index (MAI) values ranging from 0 to 20.

Reservoirs were sampled at three-week intervals beginning in January and continuing until ice conditions were unsafe in March or April. Physical and chemical features were measured at one to four sites, depending on the reservoir size. Vertical profiles of dissolved oxygen concentrations were measured. The oxygen meter was standardized in

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TABLE 1. Physical features of the reservoirs studied in southeastern Wyoming during the winters of 1986-87 and 1987-88. A range indicates variation between years.

Reservoir	Elevation (m)	Surface area (ha)	Mean depth (m)	Maximum depth (m)	Inflow (1 present, 0 absent)
Crystal	2126	37	12.2	17.9	1
East Lake	2133	18	1.8	3.2	0
Shirley Basin	2135	6	3.0	4.2	0
Granite Springs	2199	21	11.7	15.3	1
Goforth	2207	2	1.4-1.6	2.2-2.5	1
Leazenby	2234	4-8	0.2-0.4	0.5-1.0	1
King Number 1	2247	50-58	1.4-1.6	3.0-3.5	1
North Crow	2311	14-17	8.9-11.8	12.6-17.1	1
Miller Lake	2763	1	1.6-2.0	2.5-3.0	1
Sucker Lake	3166	2	0.2	0.5	1
Dipper Lake	3261	9-11	1.8-2.8	9.0-10.5	0

the laboratory and calibrated in the field before each use. To verify the reading with the oxygen meter, we collected water samples at points along the profile with a Kemmerer sampler, fixed them immediately, and determined dissolved oxygen concentration using the Azide modification of the Winkler method (American Public Health Association et al. 1975).

Average dissolved oxygen was calculated for each sampling date. Each reservoir was divided into depth strata, and the water volume in each stratum was calculated. Average oxygen concentration in each stratum was computed, and an overall weighted total oxygen concentration was determined. Winter-kill conditions were assumed to be likely when daytime average dissolved oxygen was  $<4$  mg/L (Mathias and Barica 1980).

Water inflow and outflow were recorded as present or absent on each visit. Snow and ice thickness were measured, and the mean for all sampling dates was calculated.

Measurements of variables (Table 2) for the two winters were compared using paired *t* tests (Zar 1984). Correlation analysis was used to assess relations between measured variables and average dissolved oxygen concentrations. Stepwise multiple regression and discriminant function analysis were used to identify multivariate relations. We used the Number Cruncher Statistical System (Hintze 1987) to perform the statistical analyses. The critical level chosen for all statistical procedures was  $P \leq .05$ .

## RESULTS

Substantial variation in elevation, surface

area, and water depth during winter, and the presence of inflowing water were observed among the reservoirs (Table 1). Low dissolved oxygen ( $<4$  mg/L) was common among the reservoirs (Table 2). Oxygen profiles showed typical stratification, highest concentrations being near the ice-water interface and lowest near the bottom of the reservoir. We observed average dissolved oxygen concentrations  $<4$  mg/L in two reservoirs in 1987 (Dipper Lake and Miller Lake) and in five reservoirs in 1988 (Dipper Lake, Shirley Basin, East Lake, Goforth, and Miller Lake). Water in all reservoirs was saturated with oxygen at the beginning of the winter. We did not observe gradual depletion in dissolved oxygen over the winters.

Weather data from 1955 to 1988 showed that both the 1986-87 and 1987-88 winters were about average in temperature and precipitation. Our data suggest that the winter of 1987-88 was more severe than that of 1986-87. Average snow and ice were both significantly thicker in 1988 than in 1987. Although water levels were higher in 1988 than in 1987, more of the total water volume was in the form of ice. Because of the differing conditions between the two years, we treated each year as an independent sample.

Average dissolved oxygen concentration during winter was significantly ( $P \leq .05$ ) correlated with the absence of inflow ( $r = .56$ ), elevation ( $r = -.49$ ), ice thickness ( $r = -.56$ ), snow and ice thickness ( $r = -.49$ ), and surface area of the reservoir during winter ( $r = .49$ ). When Dipper Lake was excluded from the analysis, the MAI was highly correlated ( $r = -.96$ ) with low dissolved oxygen levels.

TABLE 2. Conditions measured in the reservoirs studied in southeastern Wyoming during the winters of 1986–87 and 1987–88.

Reservoir	Mean dissolved oxygen (mg/L)	Minimum dissolved oxygen (mg/L)	Mean ice thickness (cm)	Mean snow thickness (cm)	Macrophyte abundance index
<u>1987</u>					
Crystal	7.4	7.4	33	5	
Goforth	11.6	11.3	36	1	
Leazenby	12.4	12.2	32	1	
King Number 1	11.5	11.3	37	3	
North Crow	6.9	5.9	33	5	
Miller Lake	2.3	1.4	53	12	
Dipper Lake	1.5	1.1	111	82	
<u>1988</u>					
East Lake	3.0	2.6	39	6	13
Shirley Basin	1.8	0.8	42	3	17
Granite Springs	8.7	7.1	38	3	3
Goforth	3.4	1.1	46	1	16
Leazenby	7.6	4.6	45	3	2
King Number 1	10.3	8.6	44	4	0
North Crow	6.9	5.9	33	5	5
Miller Lake	1.1	0.5	95	29	16
Sucker Lake	5.8	4.4	41	121	4
Dipper Lake	2.9	2.5	134	33	0

Stepwise multiple regression was used to determine variables that accounted for variation in average dissolved oxygen. The MAI was measured only in fall 1987, but we assumed that it remained constant over the years in our analysis. The most variability (adjusted  $R^2 = .59$ ) in average dissolved oxygen (DO) among the reservoirs was accounted for by:

$$DO = 16.1 + 3.297 I - 0.295 M - 0.004 E$$

where DO = average dissolved oxygen concentration (mg/L),  $I = 0$  if no inflow and 1 if inflow was present,  $M$  = Macrophyte Abundance Index, and  $E$  = elevation (meters). All three independent variables were significant at  $P \leq .05$ .

Discriminant function analysis was used to classify reservoirs having average dissolved oxygen  $< 4.0$  mg/L from those that had  $\geq 4.0$  mg/L. It was possible to classify 16 of 17 samples based on three variables—presence or absence of inflow, mean winter ice thickness, and MAI. Reduction in classification error attributed to models in which these variables were used was 88%. Wilk's Lambda for the discriminant function was 0.14.

## DISCUSSION

Our results indicate that the absence of inflowing water, high elevation, extensive ice and snow, small surface area, and abundant aquatic macrophytes contribute to low dissolved oxygen concentration during winter. Small ( $< 20$  ha during winter) reservoirs with no surface water inflow that are at high elevations or have abundant macrophytes ( $MAI > 12$ ) have a high risk of developing low dissolved oxygen, and subsequently fish mortality, during winter. High risk of winterkill has been associated previously with small, shallow lakes, prolonged or extensive snow and ice cover, limited water inflow, and high primary productivity (Greenbank 1945, Halsey 1968, Nickum 1970, Barica and Mathias 1979, Mathias and Barica 1980).

No previous work has provided information for small reservoirs at  $> 2100$  m above sea level. Our findings may assist managers who are trying to prevent winterkill. Several of the variables identified as having an influence on dissolved oxygen during winter—absence of inflowing water, surface area, and the abundance of aquatic plants—may be manageable under various circumstances.

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## NONGAME WILDLIFE COMMUNITIES IN GRAZED AND UNGRAZED MONTANE RIPARIAN SITES

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*Key words:* birds, small mammals, Wilson's warbler, western jumping mouse, cattle grazing, Rocky Mountains, Colorado, riparian wildlife.

The riparian zone is an important habitat type for wildlife, providing numerous foraging and breeding sites (Thomas et al. 1979b). Greater numbers and diversity of nongame wildlife have been found in riparian areas when compared with upland habitats for birds in Colorado (Knopf 1985) and small mammals in Oregon (Cross 1985). Fifty percent of the nesting bird species in the Southwest (Johnson et al. 1977) and 82% of those in northern Colorado (Knopf 1985) occur in riparian habitats. The high density and species diversity of wildlife in riparian areas have been attributed to the many structural layers of riparian vegetation and to its ecotonal nature (Thomas et al. 1979a).

Livestock grazing can alter vegetative structure and composition of riparian habitat. Ryder (1980) stated that grazing, especially by livestock and big game, frequently changes plant species composition and growth form, density of stands, vigor and seed production of plants, and insect production. Bull and Skovlin (1982) attributed to livestock grazing the paucity of deciduous woody vegetation that was required by some bird species along Oregon streams. Annual livestock grazing depressed the numbers of all small mammal species observed at Malheur National Wildlife Refuge in Oregon (Cornely et al. 1983). Small mammal species richness and diversity was higher in 11-year-old exclosures in Nevada than in adjacent riparian areas grazed by cattle (Medin and Clary 1989).

This study was designed to determine the effects of season-long cattle grazing on nongame wildlife communities in a montane

riparian zone in north central Colorado. Most research on the effects of livestock grazing on riparian bird communities has been conducted in the arid southwestern United States, and little is known about the effects of livestock grazing on birds or small mammals in more mesic environments.

### STUDY AREA AND METHODS

This study was conducted within the riparian zone bordering Sheep Creek, 75 km northwest of Fort Collins, Colorado, in the Roosevelt National Forest, at approximately 2500 m elevation. Sheep Creek varies from 3 to 4 m in width, with a riparian zone 25–75 m wide.

According to USDA Forest Service records, the Sheep Creek Grazing Allotment received extremely heavy cattle grazing pressure until the 1950s. By the late 1940s, the entire riparian area was practically denuded, with little herbaceous plant cover and only a few remnant willow (*Salix* spp.) stumps remaining. The Forest Service and Colorado Division of Wildlife built two exclosures in the fall of 1956 to protect the riparian area from livestock overgrazing in an effort to improve the fisheries habitat. A third exclosure was constructed in the spring of 1959. The three exclosures protect a total of 40 ha of the riparian zone and 2.5 km of stream. Fences consisting of three-strand barbed wire were designed to restrict only livestock access to the riparian zone. Exclosures and grazed areas were interspersed along a 5-km section of Sheep Creek (Fig. 1).

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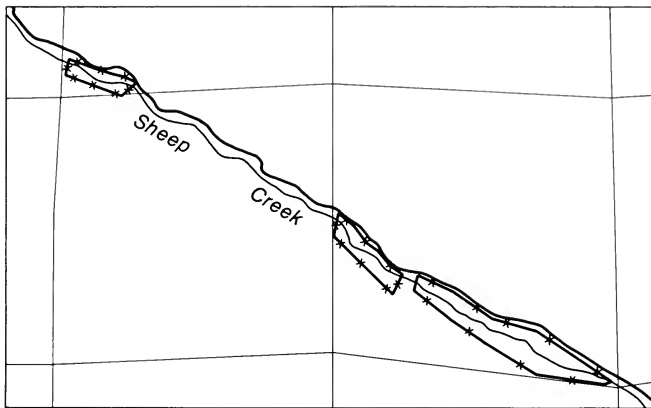


Fig. 1. Map of study area showing the Sheep Creek exclosures and adjacent grazed areas. Exclosures encompassing 40 ha of the riparian zone and 2.5 km of stream were constructed in the 1950s to protect the riparian area from overgrazing by domestic livestock. The Forest Service road that runs along the north side of the stream is shown on this map, as well as section lines for an indication of spatial scale (approximately 1 mi).

Stocking rates in the Sheep Creek Allotment have been reduced from nearly 1900 animal unit months (AUMs) in 1939 to 600 AUMs presently in the grazed area (unpublished data on file at USDA Forest Service). The allotment carrying capacity is estimated at 621 AUMs. Cattle graze the Sheep Creek Allotment season-long from approximately mid-June until mid-October. Utilization of forage by livestock was estimated from clipping vegetation at the end of the grazing season under protected cages and adjacent paired grazed plots. Cattle consumption of the current year's growth in the riparian area was 65% in both 1985 and 1986 (Schulz and Leininger 1990).

Streambank vegetation inside the exclosures is dominated by planeleaf willow (*Salix planifolia*), grasses and grasslike plants, including fowl bluegrass (*Poa palustris*), and rushes (*Juncus* spp.). Vegetation in grazed areas is composed predominantly of herbaceous species, including Kentucky bluegrass (*P. pratensis*), upland sedges (*Carex* spp.), beaked sedge (*C. rostrata*), white clover (*Trifolium repens*), and dandelion (*Taraxacum officinale*). In 1985 and 1986 total vascular vegetation cover, graminoid cover, and shrub cover in the exclosures were greater than in grazed areas (Schulz and Leininger 1990).

The Sheep Creek exclosures had nearly twice the litter buildup, and willow canopy coverage was 8.5 times greater than in grazed areas (Schulz and Leininger 1990). Upland vegetation consists of ponderosa pine (*Pinus ponderosa*) with sparse understory on north-facing slopes and big sagebrush (*Artemisia tridentata*) on south-facing slopes. Aspen (*Populus tremuloides*) is also common in more mesic areas.

Strip transects for an index of bird abundance were conducted during May–June 1986 in the exclosures and adjacent grazed areas following methods described by Verner (1985). Transects were 20 m wide and 100 m long parallel to the stream channel. Transect width ensured that all observations fell within the riparian zone. Fourteen transects (7 within the grazed areas and 7 in the exclosures) were censused 10 times during the two-month period. Counts were made between 0630 and 1000 when birds are most active and vocal. Locations of birds were marked on data forms as we walked through the middle of each transect.

Twelve snap-trap transect lines for capturing small mammals were established parallel to the stream channel (6 inside exclosures and 6 in the grazed areas). Transect lines were 114 m in length with 20 stations, one every

TABLE 1. Total bird observations on 14 strip transects in grazed and ungrazed montane riparian sites May-June 1986.

Bird species	Scientific name	Grazed	Exlosures
American Robin	<i>Turdus migratorius</i>	35	15
Broad-tailed Hummingbird	<i>Sceloporus platycercus</i>	1	2
Brown-headed Cowbird	<i>Molothrus ater</i>	4	0
Cassin's Finch	<i>Carpodacus cassinii</i>	1	2
Chipping Sparrow	<i>Spizella passerina</i>	3	5
Clark's Nutcracker	<i>Nucifraga columbiana</i>	2	0
Dark-eyed Junco	<i>Junco hyemalis</i>	7	9
<i>Empidonax</i> Flycatcher	<i>Empidonax</i> spp.	3	2
House Wren	<i>Troglodytes aedon</i>	1	0
Killdeer	<i>Chlorodreus vociferus</i>	1	0
Lincoln's Sparrow	<i>Melospiza lincolni</i>	4	13
MacGillivray's Warbler	<i>Oporornis tolmiei</i>	1	0
Mountain Chickadee	<i>Parus gambeli</i>	8	17
Mountain Bluebird	<i>Sialia currucoides</i>	2	0
Northern Flicker	<i>Colaptes auratus</i>	0	1
Pine Siskin	<i>Carduelis pinus</i>	1	0
Ruby-crowned Kinglet	<i>Regulus calendula</i>	8	8
Tree Swallow	<i>Tachycineta bicolor</i>	2	0
Warbling Vireo	<i>Vireo gilvus</i>	2	0
Western Tanager	<i>Piranga ludoviciana</i>	1	2
White-crowned Sparrow	<i>Zonotrichia leucophrys</i>	1	5
Wilson's Warbler	<i>Wilsonia pusilla</i>	0	9 <sup>a</sup>
Yellow-bellied Sapsucker	<i>Sphyrapicus varius</i>	4	0
Yellow-rumped Warbler	<i>Dendroica coronata</i>	0	2
Number of individuals		92	92

<sup>a</sup>Difference between treatments was significant at the .05 level

6 m, following Johnson (1982). The starting point of each transect line was randomly located between 10 and 20 m from the fence-line. Two Museum Special snap-traps were baited with peanut butter and set at each station. Traps were checked and reset every morning and evening at dusk. Transect lines were run for four days and nights in late July through August 1986 for a total of 1920 trap nights. Pitfall traps were also set for capturing shrews. Since trends in shrew abundance from pitfall traps were consistent with the snap-trap data, only snap-trap data is reported. All collected specimens were frozen and later identified by U.S. Fish and Wildlife Service museum personnel in Fort Collins. Shrews were identified following the key of Junge and Hoffmann (1981).

Paired *t* tests were used to compare total numbers of individuals of each bird and small mammal species by transect between grazed areas and exclosures. Homogeneity of variances was tested using Bartlett's test (Sokal and Rohlf 1981). Simpson's index of diversity (Simpson 1949) was calculated for exclosures and grazed areas using bird survey and small mammal snap-trap data. Since two communities can have the same index of diversity but

have no species in common (Samson and Knopf 1982), Morisita's index of community overlap was also calculated. Morisita's index can be interpreted as the probability of randomly drawing two individuals from two populations (i.e., grazed areas and exclosures) that both belong to the same species, relative to the probability of randomly drawing two individuals of the same species from either of the populations alone (Horn 1966).

## RESULTS

Twenty-one bird species were observed in the grazed transects, whereas 14 species were seen in the exclosures (Table 1). Eleven bird species were found in both areas. Total numbers of bird sightings were the same in both the grazed areas and the exclosures, with 92 observations. The American Robin (*Turdus migratorius*), with 35 sightings, was the most abundant species in the grazed areas, while the Mountain Chickadee (*Parus gambeli*), with 17 sightings, was the most common species in the exclosures (Table 1).

Wilson's Warbler (*Wilsonia pusilla*) was significantly more abundant ( $P = .02$ ) in the exclosure transects. Lincoln's Sparrow



TABLE 2. Total small mammals captured with Museum Special snap-traps (number of trap nights = 1920) in grazed and ungrazed montane riparian sites July–August 1986.

Mammal species	Scientific name	Grazed	Exclosures
Deer mouse	<i>Peromyscus maniculatus</i>	15	1 <sup>a</sup>
Golden-mantled ground squirrel	<i>Citellus lateralis</i>	1	0
Least chipmunk	<i>Eutamias minimus</i>	5	2
Longtail vole	<i>Microtus longicaudus</i>	0	1
Masked shrew	<i>Sorex cinereus</i>	4	5
Montane shrew	<i>S. monticolus</i>	1	9
Mountain vole	<i>M. montanus</i>	0	1
Northern pocket gopher	<i>Thomomys talpoides</i>	1	0
Western jumping mouse	<i>Zapus princeps</i>	1	22 <sup>b</sup>
Total		28	41

<sup>a</sup>Differences between treatments were significant at the .05 level.<sup>b</sup>Differences between treatments were significant at the .01 level.

(*Melospiza lincolni*) ( $P = .12$ ) also tended to be more abundant in the exclosures. Other species, e.g., Dark-eyed Junco (*Junco hyemalis*) and Ruby-crowned Kinglet (*Regulus calendula*), were equally common in grazed and ungrazed areas (Table 1).

Seven small mammal species were captured in the grazed areas, and an equal number were trapped in the exclosures (Table 2). Five small mammal species were common to both the grazed and ungrazed areas. Twenty-eight individual small mammals were trapped in the grazed area, compared with 41 in the exclosures (Table 2). The deer mouse (*Peromyscus maniculatus*), the most abundant small mammal species in the grazed area, was caught more often in the grazed areas than in the exclosures ( $P = .04$ ). In contrast, the western jumping mouse (*Zapus princeps*), the most abundant species in the exclosures, was caught more often in the exclosures than in the grazed areas ( $P = .006$ ) (Table 2). Other species such as the masked shrew (*Sorex cinereus*) appeared unaffected ( $P > .25$ ) by cattle grazing (Table 2).

Simpson's diversity index for birds and small mammals was similar for the grazed areas and the exclosures (Table 3). Morisita's index of overlap was low for both taxa, based on the similarity of the communities in grazed areas and exclosures (Table 3).

## DISCUSSION

### Breeding Birds

Bird species are differentially affected by cattle grazing in riparian areas. Mosconi and Hutto (1982) showed that some riparian bird species, such as American Robin, benefit from

TABLE 3. Comparison of nongame community parameters between grazed and ungrazed riparian sites.

Treatment	Species richness	Diversity index	Overlap
BIRD COMMUNITIES			
Grazed areas	21	0.83	15%
Exclosures	14	0.89	
SMALL MAMMAL COMMUNITIES			
Grazed areas	7	0.68	19%
Exclosures	7	0.66	

grazing, while others are negatively affected. Robins forage in short grassy areas (Bent 1949), which are more abundant in grazed areas along Sheep Creek than in the exclosures (Schulz and Leininger 1990).

Both Wilson's Warbler and Lincoln's Sparrow were common in ungrazed areas with abundant willows. Wilson's Warbler breeds in willow thickets along mountain streams (Bent 1953), while Lincoln's Sparrow prefers brushy vegetation with an understory of grasses and sedges (Bent 1968). The greater shrub coverage in the exclosures (Schulz and Leininger 1990) probably accounts for the observed differences in abundance of these two species. While small sample size is a concern in this study, other more extensive studies support these findings. In southeastern Wyoming, Lincoln's Sparrow and Wilson's Warbler dominate subalpine willow communities (Finch 1986).

Rucks (1978) stated that livestock grazing causes the replacement of shrub-nesting bird species with species showing no preference for vertical vegetation structure. Riparian

areas dominated by planeleaf willow in southeastern Wyoming contain a unique, but depauperate, assemblage of bird species (Finch 1988). Our study supports the above findings. Wilson's Warbler and Lincoln's Sparrow appear to have been replaced by ubiquitous species such as American Robin in grazed areas along Sheep Creek.

### Small Mammals

Patton (1977) stated that small rodents are probably the least understood and documented group of animals using the riparian habitat. Johnson (1982) felt that grazing increases the density of those small mammal species that require low levels of cover, while subsequently reducing the density of those requiring higher levels of cover. Our study agrees with earlier studies showing that the deer mouse is more abundant under grazed conditions (Black 1968, Johnson 1982).

In this study, the western jumping mouse was more abundant in the exclosures than in the grazed areas. According to Clark's (1971) study in western Wyoming, the western jumping mouse prefers moderately wet aspen and shrub-sedge savanna habitats within 100 m of water. This type habitat is more characteristic inside the exclosures than in grazed areas along Sheep Creek (Schulz and Leininger 1990). Our data support Cranford's (1983) suggestion that the quality and type of vegetation is more important in determining suitable habitat for the western jumping mouse than the availability of water.

While sampling only one year is a concern in this study, small mammal snap-trapping a second year would have sampled a replacement, not a stable, community. This replacement community may or may not have had the same species composition as the stable community.

### Diversity Patterns

The three levels of diversity, within habitat, between habitat, and regional, are parameters used to describe wildlife communities. Within-habitat diversity refers to the number of species within an area of uniform vegetation structure (Noss 1983) such as the Sheep Creek exclosures. Between-habitat diversity reflects the differences seen between habitats such as the entire riparian zone (grazed and ungrazed areas combined). Regional diversity refers to the diversity across the landscape (Noss 1983).

Simpson's diversity index indicated similar levels of diversity in the nongame communities in grazed areas and exclosures. This measure of within-habitat diversity reflects the number and abundance of species populations within a habitat type (Samson and Knopf 1982). Morisita's index of overlap was quite low, suggesting that, although the nongame communities in grazed areas and exclosures have a similar level of diversity, they are quite different in species composition. This value indicates a high between-habitat diversity across the entire riparian zone. Livestock grazing appears to change habitat structure (Schulz and Leininger 1990), resulting in a shift in species composition of birds and small mammals in the montane riparian zone, while maintaining the level of diversity. Riparian areas that contain unique species such as Wilson's Warbler are important contributors to regional diversity of the forest.

### Management Considerations

Riparian zones can be managed for nongame species richness by maintaining high structural diversity of vegetation. While the number of nongame species is important, managers should also use value judgments on the worth of individual species (Balda 1975). Thus, management should not maximize the numbers of two common species such as American Robin and Brown-headed Cowbird at the expense of one sensitive species such as Wilson's Warbler. Species such as Wilson's Warbler, Lincoln's Sparrow, and western jumping mouse that are sensitive to grazing pressure should be monitored as indicators of habitat change. Johnson (1982) pointed out the need to coordinate range and wildlife habitat management to ensure the existence of sensitive wildlife species that are negatively impacted by livestock grazing.

This study suggests that previous heavy cattle grazing changed the bird and small mammal community composition through reduction of shrub and herbaceous cover. More research should be done to determine the effects of different season-long intensities of grazing as well as different seasons of grazing on nongame wildlife communities.

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## NEW RECORDS OF VASCULAR PLANTS ON THE LASAL MOUNTAINS, UTAH

W. Scott Richardson<sup>1</sup>

*Key words:* vascular plants, habitat, LaSal Mountains, Utah, Grand County, San Juan County, plant records.

The LaSal Mountains are an isolated mountain range in southeastern Utah ranging in elevation from 1690 m to 3914 m. This wide range in elevation and the accompanying variety of slopes and microhabitats result in an extremely diverse flora. The most recent description of the LaSal Mountain flora was made by M. A. Franklin (unpublished data, Brigham Young University, Provo, Utah) in the early 1980s. This list consisted of historic and recent collections of plants; at the present it represents the most complete floral listing of this area.

One aspect of a recent study on the LaSal Mountain black bear population (Frost 1990, Richardson 1991) was a description of their habitat requirements. This required, among other things, making a collection of plant specimens from a wide variety of communities. Much of the collecting occurred in remote areas with difficult accessibility. As a result, I collected 14 species of vascular plants not recorded by Franklin. Seven of these species are new county records, six from Grand County (*Lithospermum multiflorum*, *Silene scouleri*, *Chimaphila umbellata*, *Sorbus scopulina*, *Ribes hudsonianum*, *Osmorhiza occidentalis*), and one from San Juan County (*Chenopodium atrovirens*). Plant nomenclature follows Welsh et al. (1987).

### APOCYNACEAE

*Apocynum androsaemifolium* L. var. *androsaemifolium*, Grand Co., UT, T26S, R25E, Sec. 5 NE 1/4, 2560 m, aspen community, 1 August 1989, S. Richardson 354 (BRY).

This was the only location on the mountain that I observed this species. Its presence in an

aspen community was somewhat unusual because it generally is found in oak and maple habitats (Arnow et al. 1980).

### BORAGINACEAE

*Lithospermum multiflorum* Torr., Grand Co., UT, T26S, R26E, Sec. 6 SW 1/4, 2439 m, ponderosa pine and Gambel oak community, 10 September 1988, S. Richardson 215 (BRY).

This is the first published record of this species in Grand County. It was found only in ponderosa pine communities on the extreme eastern portion of the mountain. Pretty stone-seed is easily identified by the presence of purple dye in the roots.

### CAPRIFOLIACEAE

*Lonicera utahensis* Wats., Grand Co., UT, T26S, R24E, Sec. 1 NW 1/4, 2744 m, aspen and white fir community, 17 August 1988, S. Richardson 165B (BRY).

Grand Co., UT, T26S, R25E, Sec. 17 NW 1/4, 3049 m, aspen and conifer community, 2 June 1989, S. Richardson 285 (BRY).

I frequently found this species on the north end of the mountain at sites with high elevations and north-facing slopes. Its occupation of sites not easily accessible explains, perhaps, why it had not been collected earlier.

*Sambucus caerulea* Raf., Grand Co., UT, T26S, R24E, Sec. 31 NE 1/4, 2378 m, mountain brush community, 18 July 1988, S. Richardson 20 (BRY).

Blue elderberry is rare on the LaSal Mountains and, as far as I know, exists only at this location. Two large plants, approximately 3 m in height, are the extent of its known distribution on this mountain.

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## CARYOPHYLLACEAE

- Silene scouleri* Hook., Grand Co., UT, T26S, R24E, Sec. 16 NE 1/4, 2805 m, aspen and conifer community, 30 June 1989, S. Richardson 336 (BRY).  
 San Juan Co., UT, T28S, R24E, Sec. 1 NW 1/4, 2744 m, Gambel oak and snowberry community, 4 August 1988, S. Richardson 103 (BRY).

Few specimens of this species have been collected in Utah (Welsh et al. 1987). The specimen (336) from Grand County represents a county record. It was not uncommon to find this species on the mountain. Both specimens were collected at elevations higher than what this species normally occupies (Welsh et al. 1987).

## CHENOPODIACEAE

- Chenopodium atrovirens* Rydb., San Juan Co., UT, T28S, R25E, Sec. 18 SW 1/4, 2652 m, Gambel oak community, 29 June 1989, S. Richardson 328 (BRY).  
 Grand Co., UT, T26S, R24E, Sec. 28 SW 1/4, 2744 m, aspen and Gambel oak community, 4 August 1989, S. Richardson 363 (BRY).

Both specimens were collected on xeric sites in association with oak. Specimen 328 is the first of this species collected in San Juan County. These specimens lacked hastately lobed leaves and occupied higher elevation sites, distinguishing it from *C. fremontii*.

## COMPOSITAE

- Artemisia biennis* Willd., Grand Co., UT, T26S, R24E, Sec. 29 SW 1/4, 2500 m, mountain brush community near a canal, 1 October 1988, S. Richardson 220 (BRY).  
 Grand Co., UT, T26S, R24E, Sec. 17 NW 1/4, 2561 m, aspen community near spring, 9 September 1989, S. Richardson 376 (BRY).

I found this species only on the north end of the mountain. Both specimens were found near water on disturbed sites, specimen 220 on a mudslide and specimen 376 in an area disturbed by livestock.

- Chrysothamnus viscidiflorus* (Hook.) Nutt. var. *viscidiflorus*, Grand Co., UT, T25S, R25E, Sec. 19 NE 1/4, 2439 m, Gambel oak community, 30 August 1989, S. Richardson 375 (BRY).

While *C. viscidiflorus* was common on the mountain, the variety *C. v. var. viscidiflorus* was found only at this location. The large leaves and glabrous stems and leaves separated it from the other varieties.

## PYROLACEAE

- Chimaphila umbellata* (L.) Barton, Grand Co., UT, T26S, R24E, Sec. 17 SE 1/4, 2927 m, aspen and conifer community, 4 September 1988, S. Richardson 207 (BRY).  
 Grand Co., UT, T26S, R24E, Sec. 16 SW 1/4, 3049 m, conifer community, 30 June 1989, S. Richardson 338 (BRY).

This was a common species at high elevations on steep, north-facing slopes. These specimens represent the first pipsissewa collected in Grand County.

## ROSACEAE

- Geum alleppicum* Jacq., Grand Co., UT, T26S, R25E, Sec. 4 NE 1/4, 2500 m, mountain brush community, 24 July 1989, S. Richardson 66, 67, 76, 77 (BRY).  
 Grand Co., UT, T26S, R25E, Sec. 17 NW 1/4, 2988 m, meadow in aspen community, 29 July 1988, S. Richardson 82 (BRY).

Few specimens of this species have been collected in Utah (Kaye Thorne, Brigham Young University Herbarium, personal communication), and these five specimens represent nearly half of the Utah material at the BYU Herbarium. This species was found only on the northeast portion of the mountain.

- Sorbus scopulina* Greene, Grand Co., UT, T26S, R24E, Sec. 1 NW 1/4, 2744 m, aspen and white fir community, 17 August 1988, S. Richardson 165C (BRY).

This is a rare species on the LaSal Mountains and was found only at two locations, both high-elevation, mesic sites on north-facing slopes. This specimen is the first recorded collection in Grand County.

## SAXIFRAGACEAE

- Ribes hudsonianum* Richards., Grand Co., UT, T26S, R24E, Sec. 29 SW 1/4, 2500 m, mountain brush community, 1 October 1988, S. Richardson 227 (BRY).

This species was seen only once and is a new record for Grand County. Its location in a mountain brush community is somewhat unusual as its typical habitat is aspen or conifer (Welsh et al. 1987). The unarmed branches and large, strongly 3-lobed leaves helped distinguish this species.

## UMBELLIFERAE

- Osmorhiza occidentalis* (Nutt.) Torr., Grand Co., UT, T26S, R24E, Sec. 7 SE 1/4, 2348 m, mountain

brush community, 13 August 1988, S. Richardson 154 (BRY).

Grand Co., UT, T26S, R24E, Sec. 21 NW 1/4, 2988 m, aspen community, 3 June 1989, S. Richardson 289 (BRY).

Found only on the northwest corner of the mountain on mesic sites, this species is a new record for Grand County.

#### LILIACEAE

*Allium biceptrum* Wats., San Juan Co., UT, T27S, R25E, Sec. 6 SW 1/4, 3049 m, open meadow in aspen community, 5 August 1988, S. Richardson 129 (BRY).

This species is uncommon in San Juan County and is found mainly in the western half of the state (Welsh et al. 1987). This is one of the few alliums to occupy high elevations (Welsh et al. 1987).

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## CHECKLIST OF THE CULTIVATED TREES OF ST. GEORGE, WASHINGTON COUNTY, UTAH

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*Key words:* cultivated trees, checklist, Washington County, Utah.

The challenge by Welsh (1987) in the introduction to *A Utah Flora* provided the impetus for writing this paper. Welsh challenges future workers to focus more attention on the cultivated plants of the state, which are numerous but poorly represented in the herbaria.

Washington County, Utah, is the most botanically diverse county in the state, both in cultivated and noncultivated species. St. George is often described as the "Palm Springs" of Utah. Its climate is milder than any other portion of the state, and palm trees and other semitropical plants attest to this fact. For this reason, the diversity of trees growing in St. George is extensive.

The following checklist is the result of a two-month intensive inventory of the street trees of St. George, the county seat and largest city in Washington County. Because of the wide diversity of trees grown in St. George, the checklist does not include all cultivated trees of Washington County. However, the majority of the species that are cultivated in the county will be represented here.

### SITE DESCRIPTION

St. George is located in Zone 8a of the new USDA zone maps and rated at Zone 10 in the Western Garden Book system. The average annual minimum temperature is 9.5–12.2 C; average rainfall is 22.3 cm per year. The growing season averages 223 days per year, and extended periods of cold weather during the winter are rare (Eubank and Brough 1979).

The soils in St. George and Washington County in general are alkaline. The four soil

types found within St. George include the Hantz and St. George silty clay loams, and the Junction and Tobler fine sandy loams (Mortensen et al. 1977).

### MATERIALS AND METHODS

The inventory was restricted to the "old city," as depicted on the 1956 revised plat of St. George. The surrounding communities of Bloomington, Bloomington Hills, Green Valley, Middleton, etc., were not part of the inventory, although a quick survey of these communities was conducted to search for species not encountered in St. George proper.

Each tree within the city right-of-way of the approximately 230 city blocks was mapped and the species, dbh (diameter at breast height), and percentage of live wood were determined. Trees with problems were also indicated. Noteworthy trees outside of the right-of-way were also mapped but designated as such. On such properties as city parks, the city cemetery, Red Hills Municipal Golf Course, and the campus of Dixie College, all trees were mapped.

Resources used to identify unknown trees include *A Utah Flora* (Welsh et al. 1987), *Manual of Cultivated Plants* (Bailey 1949), *North American Trees* (Preston 1976), *Western Garden Book* (Williamson 1979), and *The Standard Cyclopedia of Horticulture* (Bailey 1922). Local nurseries were also visited, but because many plants were mislabeled, all trees were double-checked against the above-mentioned floras and field guides and with herbarium specimens at Brigham Young University. Many specimens were not available in the herbarium for comparison and collections

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were made and deposited at the BYU Herbarium for future workers.

## RESULTS AND DISCUSSION

Approximately 3000 city trees and ca. 500 other trees outside the city right-of-way were mapped. All trees on city property and right-of-ways were entered into a data base for future reference by city parks and recreation workers. The total number of species encountered was much higher than expected, with 130 taxa in 77 genera and 38 families noted.

The three most common street trees were *Morus alba* L. (white mulberry), 16.8%; *Fraxinus velutina* Torr. (velvet ash cultivars), 12.2%; and *Gleditsia triacanthos* L. (honey locust), 5.4%.

Thirty species previously unreported for the state were discovered; they are marked with an asterisk in the checklist. A few of these have been known by some to be growing in Utah or Washington County, but they have never been collected and preserved in herbaria or reported in the literature.

An annotated species list may be obtained from the authors.

## CHECKLIST OF THE CULTIVATED TREES OF ST. GEORGE, WASHINGTON COUNTY, UTAH

Species preceded by an asterisk were either previously not known to be growing in the state of Utah or unreported in the literature and/or herbaria of the state.

### DIVISION PINOPHYTA

#### Cupressaceae

- \**Cupressocyparis leylandii* Leyland cypress  
(Dallim & Jacks.) Dallim  
*Cupressus arizonica* Greene Arizona cypress  
\**Cupressus sempervirens* L. Italian cypress  
*Juniperus chinensis* L. Chinese juniper  
*Juniperus chinensis* L. Hollywood juniper  
'Hollywood'  
*Juniperus scopulorum* Sarg. Rocky Mountain juniper  
*Platycladus orientalis* (L.) Arborvitae, Chinese thuja

#### Cycadaceae

- \**Cycas revoluta* Thurb. Sago palm, cycad

#### Ginkgoaceae

- Ginkgo biloba* L. Ginkgo, maidenhair tree

#### Pinaceae

- \**Calocedrus decurrens* (Torr.) Incense cedar  
Florin

- Cedrus atlantica* (Endl.) Atlas cedar  
Maretti ex Carr  
\**Cedrus deodara* Loud. Deodar cedar  
*Picea pungens* Engelm. Blue spruce  
\**Pinus halepensis* Mill. Aleppo pine  
\**Pinus halepensis* Mill. Mondell pine  
var. *bruttia* Henry  
*Pinus monophylla* Single-leaf pinyon  
Torr. & Frem.  
*Pinus mugo* Turra Mugo pine, Swiss mountain pine  
*Pinus nigra* Arnold Austrian pine  
\**Pinus pinca* L. Italian stone pine  
\**Pinus roxburghii* Sarg. Chir pine,  
Indian longleaf pine  
\**Pinus thumbergia* Parl. Japanese black pine

#### Podocarpaceae

- \**Podocarpus macrophylla* D. Don Yew pine

#### Taxodiaceae

- Sequoiadendron giganteum* Sequoia  
(Lindl.) Buch.

### DIVISION MAGNOLIOPHYTA

#### CLASS MAGNOLIOPSIDA

#### Aceraceae

- Acer negundo* L. Box elder  
*Acer palmatum* Thunb. Japanese maple  
*Acer saccharinum* L. Silver maple

#### Anacardiaceae

- Cotinus coggygria* Scop. Smoke tree  
*Pistacia atlantica* Desf. Mt. Atlas pistache  
\**Pistacia chinensis* Bunge Chinese pistache  
*Pistacia vera* L. Pistacio  
*Rhus typhina* L. Staghorn sumac  
*Rhus typhina* L. Fernleaf staghorn sumac  
'laciniata'

#### Aquifoliaceae

- Ilex opaca* Ait. American holly

#### Betulaceae

- Betula papyrifera* Marshall Paper birch  
*Betula pendula* Roth Weeping birch  
*Corylus avellana* L. 'Contorta' Harry Lauder's walking stick

#### Bignoniaceae

- Catalpa speciosa* Warder Catalpa, Indian cigar tree  
*Chilopsis linearis* (Cav.) Sweet Desert willow

#### Ebenaceae

- Diospyros* sp. Persimmon

#### Elaeagnaceae

- Elaeagnus angustifolia* L. Russian olive

#### Fagaceae

- Quercus pauciloba* Rydb. Wavyleaf live oak  
*Quercus turbinella* Greene Canyon live oak  
*Quercus* spp. Oak hybrids

Hamamelidaceae		<i>Fraxinus velutina</i> Torr.	Velvet ash
<i>Liquidambar styraciflua</i> L.	Sweetgum	* <i>Ligustrum lucidum</i> Ait.	Glossy privet
Hippocastanaceae		* <i>Olea europaea</i> L.	Olive
<i>Aesculus hippocastanum</i> L.	Horsechestnut	Platanaceae	
Juglandaceae		<i>Platanus x acerifolia</i> Willd.	Sycamore, London plane tree
<i>Carya illinoensis</i> (Wangenh.) K. Koch	Pecan	<i>Platanus occidentalis</i> L.	American sycamore
<i>Juglans nigra</i> L.	Black walnut	* <i>Platanus racemosa</i> Nutt.	California sycamore
<i>Juglans regia</i> L.	English walnut	Rhamnaceae	
Lauraceae		<i>Ziziphus jujuba</i> Miller	Jujube
* <i>Laurus nobilis</i> L.	Sweetbay	Rosaceae	
Leguminosae		<i>Crataegus</i> c.f. <i>laccigata</i> (Poir.) DC	English hawthorne
<i>Albizia julibrissin</i> Durazz.	Mimosa, silk tree	* <i>Eriobotrya japonica</i> Lindl.	Loquat
<i>Caesalpinia gilliesii</i> (Wallich) Dietr.	Bird-of-paradise	* <i>Eriobotrya deflexa</i> (Hemsl.) Nakai	Bronze loquat
<i>Cercis canadensis</i> L.	Redbud	<i>Malus floribunda</i> Sieb. ex Van Houtte	Flowering crabapple
<i>Gleditsia triacanthos</i> L.	Honey locust	<i>Malus pumila</i> Miller	Apple
<i>Laburnum anagyroides</i> Mebicus	Goldenchain	<i>Malus</i> sp.	Crabapple
<i>Parkinsonia aculeata</i> L.	Paloverde	<i>Photinia x fraseri</i> Dress.	Photinia
<i>Prosopis glandulosa</i> Torr.	Honey mesquite	<i>Prunus armeniaca</i> L.	Apricot
<i>Prosopis pubescens</i> Benth.	Screwbean mesquite	<i>Prunus avium</i> L.	Cherry
* <i>Robinia x ambigua</i> Poir.	Idaho locust	<i>Prunus x bleriana</i> Andre.	Flowering plum
'Idahoensis'		* <i>Prunus caroliniana</i> Ait.	Carolina laurel cherry
<i>Robinia pseudoacacia</i> L.	Black locust	<i>Prunus cerasifera</i> Ehrh.	Flowering plum
<i>Sophora japonica</i> L.	Japanese pagoda tree	<i>Prunus cerasus</i> L.	Pie cherry, sour cherry
<i>Wisteria</i> sp.	Wisteria	<i>Prunus domestica</i> L.	Plum
Lythraceae		<i>Prunus dulcis</i> (Miller) D. A. Webb	Almond
<i>Lagerstroemia indica</i> L.	Crape myrtle (not crepe myrtle)	<i>Pyrus calleryana</i> Decne.	Bradford pear, Callery pear
Magnoliaceae		<i>Pyrus communis</i> L.	Pear
<i>Liriodendron tulipifera</i> L.	Tulip tree, yellow poplar	Salicaceae	
* <i>Magnolia grandiflora</i> L.	Southern magnolia	<i>Populus alba</i> L.	White poplar
<i>Magnolia soulangeana</i> Soul.-Bod.	Showy magnolia	<i>Populus fremontii</i> Wats.	Fremont poplar, Fremont cottonwood
Malvaceae		<i>Populus x canadensis</i> Moench	Carolina poplar, cottonwood
<i>Hibiscus syriacus</i> L.	Rose-of-Sharon	<i>Populus nigra</i> L. var. <i>italica</i> Duroi	Lombardy poplar
Meliaceae		<i>Populus tremuloides</i> Michx.	Quaking aspen
<i>Melia azedarach</i> L.	Texas umbrella, chinaberry tree	<i>Salix babylonica</i> L.	Weeping willow
Moraceae		<i>Salix laevigata</i> Bebb	Red willow
* <i>Broussonetia papyrifera</i> L'Her.	Paper mulberry	<i>Salix matsudana</i> Koidz.	Globe willow
<i>Ficus carica</i> L.	Fig	<i>Salix matsudana</i> Koidz. 'Tortuosa'	Corkscrew willow
<i>Maclura pomifera</i> (Raf.) Schneider	Osage orange	Sapindaceae	
<i>Morus alba</i> L.	White mulberry, fruitless mulberry	<i>Koeleruteria paniculata</i> Laxmann	Goldenrain tree
<i>Morus nigra</i> L.	Black mulberry	<i>Sapindus saponaria</i> L. var. <i>drummondii</i> (Hook. & Arn.) Benson	Soapberry
Myrtaceae		Simaroubaeae	
* <i>Eucalyptus nicholii</i> Maiden & Blakely	Willowleaf eucalyptus	<i>Ailanthus altissima</i> (Miller) Swingle	Tree-of-heaven
* <i>Eucalyptus polyanthemos</i> Schauer	Silver dollar gum	Tamaricaceae	
* <i>Feijoa sellowiana</i> Berg.	Pineapple guava	<i>Tamarix parviflora</i> DC	Salt cedar, tamarisk
Oleaceae		Tiliaceae	
<i>Fraxinus excelsior</i> L.	European ash	<i>Tilia cordata</i> L.	Small-leaved European linden
* <i>Fraxinus oxycarpa</i> Willd.	Raywood ash	<i>Tilia europaea</i> L.	European linden
'Raywood'			

## Ulmaceae

*Celtis occidentalis* L.  
*Ulmus americana* L.  
*Ulmus procera* Salisb.  
*Ulmus pumila* L.

Hackberry  
 American elm  
 English elm  
 Siberian elm

## Verbenaceae

*Vitex agnus-castus* L.

Chaste tree

DIVISION MAGNOLIOPHYTA  
 CLASS LILIOPSIDA

## Agavaceae

*Yucca brevifolia* Engelm.  
*Yucca* sp.

Joshua tree

## Palmaeae

\**Chamaecrops humilis* L. Mediterranean fan palm  
 \**Phoenix dactylifera* L. Date palm  
 \**Trachycarpus fortunei* Wendl. Windmill palm  
*Washingtonia filifera* (L. Linden) California fan palm  
 Wendl.  
 \**Washingtonia robusta* Wendl. Mexican fan palm

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## INTERMOUNTAIN CONSORTIUM FOR ARIDLANDS RESEARCH

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Dr. E. Durant McArthur, President

### INTERMOUNTAIN CONSORTIUM FOR ARIDLANDS RESEARCH FORMED

The first (organizational) meeting of the Intermountain Consortium for Aridlands Research (ICAR) was held in Salt Lake City on February 21, 1991. ICAR was established to promote, facilitate, and coordinate research and education on arid ecosystems in the Intermountain area. Charter institutions include these universities and federal and state agencies: Brigham Young University; Southern Utah University; University of Nevada-Reno; University of Utah; Utah State University; Wayne State University; Weber State University; Desert Research Institute; U.S. Department of the Interior, Bureau of Land Management, Utah State Office; U.S. Department of Agriculture, Forest Service, Intermountain Research Station; U.S. Department of the Interior, National Park Service, Great Basin National Park; and Utah Division of Wildlife Resources.

#### ICAR will

- promote research and education on arid-land ecosystems
- facilitate interactions among aridlands scientists
- develop programs for educating the public on the ecological values and economic role of aridlands
- provide coordination between federal, state, and private agencies and institutions interested in Intermountain arid-lands research and education
- identify high priority research needs in the Intermountain West arid zone
- identify research facilities and long-term data bases in the Intermountain West arid zone
- utilize the long-term research studies conducted at the Desert Experimental Range (87-square-mile area with 54 years of data) and elsewhere as a basis for development of research related to global change

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## IMPACTS OF BLACK-TAILED PRAIRIE DOG RODENTICIDES ON NONTARGET PASSERINES

Anthony D. Apa<sup>1,3</sup>, Daniel W. Uresk<sup>2,4</sup>, and Raymond L. Linder<sup>1</sup>

**ABSTRACT.**—In 1983 zinc phosphide, strychnine with prebait, and strychnine without prebait were applied to black-tailed prairie dog (*Cynomys ludovicianus*) colonies in west central South Dakota. Short-term (four days later) and long-term (one year later) impacts of the rodenticides on Horned Larks (*Eremophila alpestris*) and other granivorous birds inhabiting prairie dog colonies were evaluated. Horned Larks and 49 other bird species were observed. Immediate impacts reduced Horned Lark relative densities 66% with strychnine only and 55% with prebaited strychnine. Zinc phosphide caused no measurable reduction. Horned Larks showed no long-term direct impacts. Indirect negative impacts occurred through habitat changes following prairie dog control. The granivorous guild showed no short- or long-term effects.

**Key words:** *Cynomys ludovicianus*, *Eremophila alpestris*, granivorous guild, zinc phosphide, strychnine.

Poisons applied to oats are the past and present primary tool for black-tailed prairie dog (*Cynomys ludovicianus*) control. Strychnine was introduced into the United States about 1847, and its success as a rodenticide has varied (Crabtree 1962). The alkaloid form on grain was recommended by the U.S. Department of Agriculture at the beginning of the century (Merriam 1902, Crabtree 1962). Inconsistent treatment effects in certain situations and potential hazards to many nontarget species (Tietjen 1976) have caused concern.

Zinc phosphide was introduced as a vertebrate pest control agent in 1943 due to strychnine shortages during World War II (Crabtree 1962). Following replenished supplies of strychnine and the development of sodium monofluoroacetate (Compound 1080), use of zinc phosphide as a field rodenticide was curtailed until it was developed specifically for black-tailed prairie dog control in 1976

(Tietjen 1976). Since 1976, zinc phosphide has been the only rodenticide available for prairie dog control when there is federal involvement.

Several granivorous passerines inhabit black-tailed prairie dog colonies (Agnew et al. 1986). Birds residing on prairie dog colonies that could suffer death or illness from poison consumption are those of seed-eating guilds (Root 1967, Creighton 1974.) This guild could consume treated grains. Tietjen (1976) observed Horned Larks (*Eremophila alpestris*) and Mourning Doves (*Zenaida macroura*) on zinc phosphide-treated prairie dog colonies, but observations after treatment did not locate any sick or dead birds. In contrast, Hegdal and Gatz (1977a) found significant mortality of nontarget seed-eating birds, especially Horned Larks and Mourning Doves, when strychnine-treated grain was applied to Richardson's ground squirrel (*Spermophilus richardsonii*)

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colonies. The U.S. Department of Interior (1956) acknowledged that nontarget losses occurred following exposure to strychnine and recommended that attempts be made to minimize the effects.

Quantitative estimates that evaluate poison impacts on avian residents from prairie dog control have not been fully documented. The objectives of this study were to evaluate (1) short- and long-term effects of zinc phosphide (with bait), strychnine with bait, and strychnine without bait on Horned Larks and the granivorous avian guild and (2) compare three rodenticide treatments. Immediate effects on birds by the three rodenticide treatments have been reported by Uresk et al. (1988).

#### STUDY AREA

The study area is located on Badlands National Park and Buffalo Gap National Grasslands in west central South Dakota. Climate is considered semiarid with an average annual precipitation of 40 cm at the Cedar Pass Visitors Center, Badlands National Park. Approximately 80% of the precipitation falls as thundershowers during April to September, and rainfall can be localized or cover large areas. Temperatures range from  $-5^{\circ}\text{C}$  in January to  $43^{\circ}\text{C}$  in July, with an average annual temperature of  $10^{\circ}\text{C}$ .

Raymond and King (1976) described the soils on the area as sedimentary deposits of clay, silt, gravel, and volcanic ash. Topographic features consist of rugged pinnacles, vegetated table top buttes, creek gullies, and grassland basins. Gently rolling grasslands are located in the northern portion of the study area with elevation ranging from 700 to 1000 m.

The vegetation consists of a mosaic of native grasses, forbs, shrubs, and isolated trees. Dominant grasses include bluegrama (*Bouteloua gracilis*), buffalograss (*Buchloe dactyloides*), needleleaf sedge (*Carex cleocharis*), and western wheatgrass (*Agropyron smithii*). Common forbs include scarlet mallow (*Sphaeralcea coccinea*), American vetch (*Vicia americana*), dogweed (*Dyssodia papoposa*), sage (*Salvia reflexa*), and prairie sunflower (*Helianthus petiolaris*). The dominant shrub species is pasture sagebrush (*Artemisia frigida*). Nonnative grasses include cheat-

grass (*Bromus tectorum*) and Japanese chess (*B. japonicus*). (Scientific names of plants follow Nickerson et al. 1976 and Van Bruggen 1976.) Native herbivores are black-tailed prairie dog, mule deer (*Odocoileus hemionus*), Rocky Mountain bighorn sheep (*Ovis canadensis*), American bison (*Bison bison*), pronghorn (*Antilocapra americana*), black-tailed jackrabbit (*Lepus californicus*), and white-tailed jackrabbit (*L. townsendii*). Small rodents include deer mouse (*Peromyscus maniculatus*) and grasshopper mouse (*Onychomys leucogaster*). Livestock are not present in the Park, but bison graze all year. Cattle are allowed to graze the National Grasslands six months during the growing season each year.

#### METHODS

Eighteen sites on 15 prairie dog colonies were sampled in 1983 and 1984 with 9 treatment sites and 9 controls (Uresk et al. 1986). Sites were clustered into three major areas, and each rodenticide treatment had 3 treated and 3 control sites. Zinc phosphide with bait was applied to the area within Badlands National Park because administrative restraints did not allow the use of strychnine. Four of the zinc phosphide (2 treatment and 2 control) sites were clustered and paired on a prairie dog colony of approximately 600 ha. The remaining treatment prairie dog colony was located northwest of the aforementioned larger colony, and the control colony was northeast of the larger colony in the Buffalo Gap National Grasslands. Strychnine with and without bait treatment was randomly assigned to the two areas on the National Grasslands. The area with baited strychnine was located east and south of Scenic, South Dakota. All strychnine treatment and control sites were on isolated towns ranging from 12 to 283 ha. Within each treatment regime, treatment or control designation was determined randomly except when the National Park Service imposed administrative restrictions.

Avian populations were sampled on 18 permanent  $805 \times 62\text{-m}$  (4.9 ha) belt transects, one on each site. Relative densities of bird species were estimated using a modification of techniques developed by Emlen (1971, 1977) and Rotenberry (1982). The observer walked

the transect line and counted birds up to 31 m on either side of the line. Sampling began one-half hour after sunrise and continued for approximately 4–5 hours; average walking time was 15–25 minutes per transect. Sampling was conducted on four consecutive days for each sampling session. Birds hovering over and/or flying over the transect were tallied. In 1983 four pretreatment sampling sessions, prior to poisoning prairie dogs, were conducted in June, July, August, and early September. The sampling session in early September occurred one week prior to poisoning. The first posttreatment session in late September commenced four days after treatment to evaluate short-term treatment effects. Four posttreatment sampling sessions were conducted in June, July, August, and September of 1984 to evaluate long-term treatment effects.

#### Bait Formulation and Application

Poison application was in accordance with federal label instructions. The untreated oats (prebait) and the poisoned oats were applied from 3-wheel drive ATVs fitted with bait dispensers (Schenbeck 1982). Smaller acreages were treated by hand using teaspoons (H. P. Tietjen, USFWS, Denver, Colorado, personal communication).

Prebait consisted of four grams of high-quality, untreated, steam-rolled oats applied at each prairie dog burrow. Three sites were prebaited on 20 September 1983 and three on 21 September 1983. A minimum of 95% of the burrows were prebaited. Prebait was applied ( $<0.01 \text{ m}^2$  area) at edges of prairie dog mounds. Three days after prebait application three sites were treated with 4 g of 2.0% active zinc phosphide steam-rolled oats. On 23 September 1983 three additional sites were treated with 8 g of 0.5% strychnine alkaloid steam-rolled oats per burrow. The last three sites were treated with strychnine oats on 24 September 1983 but were not prebaited.

#### Statistical Analyses

Analysis of covariance was used to compare each treated group (cluster) of sites with its respective control group. Applications of repeated measures were examined but required constant response through time; i.e., no interaction between time and treatment. These data did not show a constant response through

time and had interactions; therefore we used covariance adjustments for individual post-treatment sampling sessions. Pretreatment observations were used as covariates. Effect of rodenticide treatment for each time point was estimated as the covariance-adjusted difference between treated and control sites for each rodenticide. After obtaining an overall rejection of the hypothesis of no treatment effect, contrasts for each rodenticide treatment compared to its control were evaluated for significance based on a variance estimated only from the sites in each cluster (variance was heterogeneous among clusters). If the correlation between pretreatment and post-treatment observations was not significant ( $\alpha < 0.20$ ), then estimates of treatment effects were based on the difference between post-treatment and pretreatment observations (repeated measures). This analysis uses the interaction between time and treatment as the indicator of the significant change due to treatment (Green 1979). Rodenticides were compared by forming pairwise contrasts of the contrasts obtained for the individual rodenticide treatments. Randomization procedures (Edington 1980, Romesburg 1981) based on 10,000 random permutations of the data pairs among treatment groups were used to estimate statistical significance of the various contrasts. Variance of a contrast was calculated as the sum of the variances of the means in the contrast, with calculated individual variances based on the covariance and homogeneous variance assumptions appropriate for the particular variable.

Because omission of any effect due to poisoning was considered more serious than the potential incorrect declaration of a significant treatment effect, Type II error protection was produced by testing each contrast individually. However, some Type I error protection was afforded by testing individual contrasts only after first observing a significant ( $P = .10$ ) overall test of treatment differences using analysis of covariance (Carmer and Swanson 1973). Individual contrasts were considered biologically significant at  $P = .20$ . Although admittedly unconventional, for the number of sites available for study, this significance criterion produces a power (probability of detecting a true difference) of approximately 0.80 for a contrast twice as large as its standard error. This was considered a reasonable

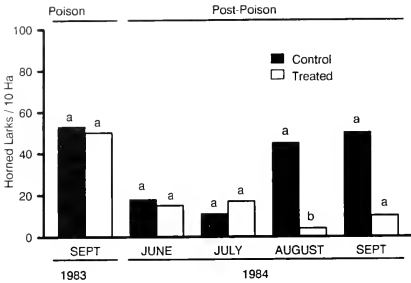


Fig. 1. Seasonal comparisons of Horned Lark relative densities on zinc phosphide-treated and control sites from initial treatment in September 1983 through September 1984. Adjusted means are from covariance analysis. Statistical analysis was conducted on posttreatment minus pretreatment. Means followed by the same letter by date are not significant at  $\alpha = 0.20$  after F-protection at  $\alpha = 0.10$ .

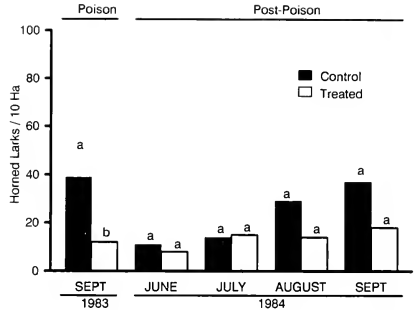


Fig. 2. Seasonal comparisons of Horned Lark relative densities on strychnine-treated and control sites from initial treatment in September 1983 through September 1984. Adjusted means are from covariance analysis. Statistical analysis was conducted on posttreatment minus pretreatment. Means followed by the same letter by date are not significant at  $\alpha = 0.20$  after F-protection at  $\alpha = 0.10$ .

combination of Type I and Type II error protection for this study (Carmer 1976).

## RESULTS

### Passerines

Forty-six species of birds were observed on all sites in 1983 and 40 in 1984. Eighteen bird species present on the sites were different between years. Total bird observations in 1983 were 8639; 65% of the sample consisted of Horned Larks, and 14% were Western Meadowlarks. However, in 1984 total bird observations were 5965, with Horned Larks accounting for 56% and Western Meadowlarks 18% of the sample. Unidentified species were less than 1% of the sample either year.

### Horned Larks

There was no difference ( $P = .977$ ) in the number of Horned Larks between treatment and control sites four days after application of zinc phosphide (Fig. 1). Relative densities of Horned Larks on the treatment sites were 50/10 ha, and control sites were 52/10 ha. No differences were found in relative densities between treated and control sites in June ( $P = .479$ ) and July ( $P = .486$ ) of 1984. The relative densities of Horned Larks in August 1984 were 93% higher (44/10 ha) on control sites than on treated sites (3/10 ha) ( $P = .190$ ). In September 1984 similar trends were

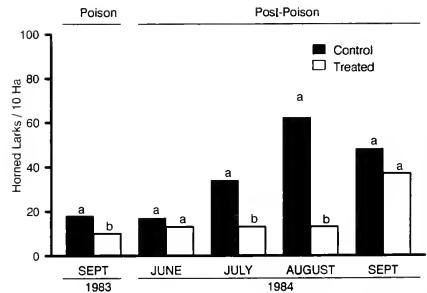


Fig. 3. Seasonal comparisons of Horned Lark densities on prebaited strychnine-treated and control sites from initial treatment in September 1983 through September 1984. Adjusted means are from covariance analysis. Statistical analysis was conducted on posttreatment minus pretreatment. Means followed by the same letter by date are not significant at  $\alpha = 0.20$  after F-protection at  $\alpha = 0.10$ .

observed, but overall significant treatment effects were not evident ( $P > .10$ ).

In 1983 Horned Lark densities were reduced 66% ( $P = .109$ ; Fig. 2) on the strychnine only sites. No differences in relative densities for the Horned Lark occurred from June through September 1984 between treated and control sites ( $P > .20$ ), indicating no long-term impacts.

Strychnine with prebait reduced Horned Lark relative densities 45% ( $P = .128$ ; Fig. 3). By June 1984 Horned Lark densities were the

TABLE 1. Comparison of effects of zinc phosphide (ZnP) and strychnine (S-9) on Horned Lark relative densities/10 ha.

Period	Zinc phosphide versus strychnine			Significance <sup>c</sup>
	Adjusted effect			
	ZnP <sup>a</sup>	S-9 <sup>a</sup>	Main effect <sup>b</sup>	
1983				
September	1 ± 19	30 ± 19	31 ± 27	0.254
1984				
June	-5 ± 7	-4 ± 7	-1 ± 10	0.948
July	-6 ± 5	-2 ± 5	4 ± 7	0.717
August	-31 ± 3	3 ± 11	33 ± 11	0.183
September	-38 ± 20	-25 ± 20	-13 ± 28	NS <sup>d</sup>

<sup>a</sup>Effect adjusted through subtraction or analysis of covariance (mean ± standard error).<sup>b</sup>Main effect calculated by difference of poisons.<sup>c</sup>Probabilities calculated for contrasts in randomization test ( $\alpha = 0.20$ ) based on variance heterogeneity after a significant F-protection at  $\alpha = 0.10$  by analysis of variance or covariance.<sup>d</sup>F-protection at  $\alpha = 0.10$ .

TABLE 2. Comparison of effects of zinc phosphide (ZnP) and prebaited strychnine (PS-9) on Horned Lark relative densities/10 ha.

Period	Zinc phosphide versus prebaited strychnine			Significance <sup>c</sup>
	Adjusted effect			
	ZnP <sup>a</sup>	PS-9 <sup>a</sup>	Main effect <sup>b</sup>	
1983				
September	1 ± 19	-29 ± 19	30 ± 27	0.280
1984				
June	-5 ± 7	-2 ± 7	-2 ± 10	0.774
July	-6 ± 5	-20 ± 5	26 ± 7	0.020
August	-31 ± 3	-84 ± 11	53 ± 11	0.062
September	-38 ± 20	-32 ± 20	-6 ± 28	NS <sup>d</sup>

<sup>a</sup>Effect adjusted through subtraction or analysis of covariance (mean ± standard error).<sup>b</sup>Main effect calculated by difference of poisons.<sup>c</sup>Probabilities calculated for contrasts in randomization test ( $\alpha = 0.20$ ) based on variance heterogeneity after a significant F-protection at  $\alpha = 0.10$  by analysis of variance or covariance.<sup>d</sup>F-protection at  $\alpha = 0.10$ .

same on treated and control sites ( $P = .746$ ). In July 1984, 33 Horned Larks/10 ha were observed on the controls, while only 13/10 ha were on the treated sites ( $P = .011$ ). In August relative densities of Horned Larks on control sites were 81% higher (62/10 ha) than on the treated sites (12/10 ha) ( $P = .002$ ). By September 1984, however, there were no differences in relative densities between treated and control sites ( $P > .10$ ).

### Rodenticide Evaluation

The impact of zinc phosphide on Horned Larks was not different from that of strychnine only ( $P = .254$ ; Table 1). In June and July 1984 there was no difference between the effects of zinc phosphide and strychnine on Horned Larks ( $P = .948$  and  $P = .717$ , respectively). In August 1984 the effect of zinc phosphide was greater than that of strychnine ( $P = .183$ );

however, in September 1984 no differences occurred between zinc phosphide and strychnine ( $P < .10$ ).

A comparison of zinc phosphide and prebaited strychnine showed no differences in Horned Lark relative densities ( $P = .280$ ) in September 1983 (Table 2). No differences were found between rodenticides in June 1984 ( $P = .774$ ). During July and August 1984 differences were observed between zinc phosphide and prebaited strychnine ( $P = .020$  and  $P = .062$ , respectively). Zinc phosphide showed less impact on Horned Lark densities than prebaited strychnine. However, in September 1984 no differences between zinc phosphide and strychnine were found ( $P > .10$ ).

Strychnine only and prebaited strychnine were compared in September 1983, and no difference ( $P = .964$ ) was found (Table 3). In June 1984 there was a difference of 2

TABLE 3. Comparison of effects of strychnine only (S-9) and prebaited strychnine (PS-9) on Horned Lark relative densities/10 ha.

Period	Strychnine versus prebaited strychnine			Significance <sup>c</sup>
	Adjusted effect			
	S-9 <sup>a</sup>	PS-9 <sup>a</sup>	Main effect <sup>b</sup>	
1983				
September	-30 ± 19	-29 ± 19	-1 ± 27	0.964
1984				
June	-4 ± 7	-2 ± 7	-2 ± 10	0.834
July	2 ± 5	-20 ± 5	22 ± 7	0.066
August	3 ± 11	-84 ± 11	87 ± 16	0.006
September	-25 ± 20	-32 ± 20	7 ± 25	NS <sup>d</sup>

<sup>a</sup>Effect adjusted through subtraction or analysis of covariance (mean ± standard error).<sup>b</sup>Main effect calculated by difference of poisons.<sup>c</sup>Probabilities calculated for contrasts in randomization test ( $\alpha = 0.20$ ) based on variance heterogeneity after a significant F-protection at  $\alpha = 0.10$  by analysis of variance or covariance.<sup>d</sup>F-protection at  $\alpha = 0.10$ .

TABLE 4. Bird species observed and included in the granivorous guild in 1983 and 1984 on all 18 study sites in west central South Dakota.

American Crow ( <i>Corvus brachyrhynchos</i> )
American Goldfinch ( <i>Carduelis tristis</i> )
American Robin ( <i>Turdus migratorius</i> )
Black-billed Magpie ( <i>Pica pica</i> )
Chestnut-collared Longspur ( <i>Calcarius ornatus</i> )
Common Grackle ( <i>Quiscalus quiscula</i> )
European Starling ( <i>Sturnus vulgaris</i> )
Grasshopper Sparrow ( <i>Ammodramus saccannarum</i> )
Lark Bunting ( <i>Calamospiza melanocorys</i> )
Lark Sparrow ( <i>Chondestes grammacus</i> )
Mourning Dove ( <i>Zenaidura macroura</i> )
Red-winged Blackbird ( <i>Agelaius phoeniceus</i> )
Ring-necked Pheasant ( <i>Phasianus colchicus</i> )
Rock Dove ( <i>Columba livia</i> )
Savannah Sparrow ( <i>Passerculus sandwichensis</i> )
Sharp-tailed Grouse ( <i>Tympanuchus phasianellus</i> )
Vesper Sparrow ( <i>Poocetes gramineus</i> )
Western Meadowlark ( <i>Sturnella neglecta</i> )

Horned Larks/10 ha between the two treatments ( $P = .834$ ). Differences for these two treatments were observed in July (22 Horned Larks/10 ha) and August (87 Horned Larks/10 ha) 1984 ( $P = .066$  and  $P = .006$ , respectively). Sites with prebaited strychnine showed the greatest reduction in Horned Lark relative densities. In September 1984 no differences in impacts between strychnine and prebaited strychnine were found ( $P > .10$ ).

#### Granivorous Avian Guild

Seed-eating birds were combined into a guild because of small sample sizes (Table 4). In September 1983 no treatment effect ( $P > .10$ ) was found on the seed-eating guild with Horned Larks excluded. This was also

true for June ( $P = .754$ ), July ( $P = .300$ ), and September ( $P = .841$ ) 1984.

In August 1984 seed-eating bird densities on the zinc phosphide-treated sites were similar ( $P = .454$ ) to the controls. On the strychnine-treated sites 4 birds/10 ha were found, and even though 5 birds/10 ha were observed on the control sites, the means were significantly different ( $P = .181$ ). The prebaited strychnine treatment means were also higher, with 20 birds/10 ha on the treated sites and 3 birds/10 ha on the controls ( $P = .030$ ).

#### Rodenticide Evaluation

In August 1984 the effective difference of the prebaited strychnine treatment was larger than for the zinc phosphide (-30 birds/10 ha) ( $P = .173$ ) and strychnine (-22) ( $P = .011$ ) treatments (Table 5). Zinc phosphide and strychnine impacts on the seed-eating guild were similar (-8) ( $P = .721$ ).

#### DISCUSSION

##### Bait Availability

More poisoned grain remained on the prairie dog mounds following poisoning with strychnine than with zinc phosphide (Apa et al. 1990). This phenomenon is most likely related to the "taste factor" that accompanies strychnine and zinc phosphide. Prairie dogs more readily consume zinc phosphide. Also, the time factor involved before a toxic reaction occurs after poison consumption (Crabtree 1962) could influence bait quantities remaining. The toxic reaction time is faster for strychnine than zinc phosphide; therefore, more

TABLE 5. Comparison of effects of zinc phosphide (ZnP) and strychnine only (S-9), zinc phosphide and prebaited strychnine (PS-9), and strychnine only and prebaited strychnine on seed-eating bird relative densities/10 ha.

	August 1984					
	Zinc phosphide versus Strychnine versus prebaited strychnine					
	ZnP	S-9	ZnP	PS-9	S-9	PS-9
Adjusted effect <sup>a</sup>	-18 ± 7	-10 ± 5	-18 ± 5	-12 ± 10	10 ± 3	12 ± 8
Main effect <sup>b</sup>	-8 ± 7		30 ± 11		-22 ± 9	
Significance <sup>c</sup>	0.721		0.173		0.011	

<sup>a</sup>Effect adjusted through analysis of covariance (mean ± standard error).<sup>b</sup>Main effect calculated by difference of poisons.<sup>c</sup>Probabilities calculated for contrasts in randomization test ( $\alpha = 0.20$ ) based on variance heterogeneity after significant F-protection at  $\alpha = 0.10$  by analysis of covariance.

zinc phosphide could be consumed. These factors definitely affect availability of poisoned grain on prairie dog mounds following treatment.

#### Horned Larks

Treatments using zinc phosphide showed no direct impact on Horned Larks, but the two strychnine treatments did impact them. Strychnine is known for its avicidal efficacy (Courtsal 1983), but sparse documentation exists on its direct effects on birds. In this study, immediate direct losses were observed, and Horned Lark carcasses were found on the poisoned towns soon after poison application. Decreased relative densities of Horned Larks with both strychnine treatments were a result of direct poison toxicity and the large quantities of strychnine grain that remained on the mounds following post-treatment. The excess strychnine-treated grain was available to Horned Larks until bait disappeared or toxic effects were reduced. Hegdal and Gatz (1977a) found strychnine doses lethal to birds two months after poison application, resulting in significant reductions in Horned Lark populations in Wyoming.

There were no significant reductions in Horned Lark relative densities from zinc phosphide treatment because: (1) poison grain remaining was low, (2) birds have an aversion to black-colored foods (Rudd and Genelly 1956), and (3) birds have a negative sensory response to zinc phosphide (Siegfried 1968). Reduced impacts by zinc phosphide on birds have also been reported by Tietjen (1976), Tietjen and Matschke (1982), and Matschke et al. (1983). We believe zinc phosphide to be the preferred rodenticide for minimizing impacts on Horned Larks.

Indirect impacts on Horned Larks resulted from habitat changes. In 1984, when juveniles fledged, differences were observed between the control and treated sites. After the 1983 treatment of prairie dog colonies in the fall, Horned Larks nested on what appeared to be potential optimum habitat in spring 1984. Optimum nesting habitat consists of semibare or heavily grazed situations (Pickwell 1931, Dubois 1935, Bent 1968, Giezantanner 1970, Creighton 1974). As summer progressed, prairie dogs were not available on treated sites to graze the spring growth. We observed many grasses (nonnative grasses and western wheatgrass) and forbs (prairie sunflower) that had obtained heights above the line of sight of ground-dwelling birds. Plant biomass increased and provided suitable habitat for Western Meadowlark, Lark Bunting, and Chestnut-collared Longspur (Giezantanner 1970).

In contrast, optimum habitat for Horned Larks was maintained by grazing of prairie dogs and other herbivores on the control sites throughout 1984. The low levels of prairie dog control achieved on the strychnine-treated towns (Apa et al. 1990) allowed surviving prairie dogs to consume vegetation and maintain optimum habitat for Horned Larks.

#### Granivorous Avian Guild

No immediate impacts on granivorous seed-eating birds were found, although we must acknowledge confounding individual effects that could influence results since we combined several granivorous species. Hegdal and Gatz (1977a) indicated that strychnine posed a threat to Red-winged, Yellow-headed (*Xanthocephalus xanthocephalus*), and Brewer's

(*Euphagus cyanocephalus*) Blackbirds; Vesper Sparrows; Western Meadowlarks; and Mourning Doves. Poisoned grains treated with zinc phosphide also posed a lesser threat to other seed-eating birds (Tietjen 1976, Hegdal and Gatz 1977b).

#### ACKNOWLEDGMENTS

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MORPHOLOGICAL VARIABILITY AND CELL WALL COMPOSITION OF  
*PHAEODACTYLUM TRICORNUTUM* (BACILLARIOPHYCEAE)

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**ABSTRACT.**—Five isolates of *Phaeodactylum tricornutum* Bohlin were examined in light and transmission electron microscopes. Although isolated from widely separated sites including both coastal marine and inland saline habitats, the morphology of the siliceous frustules of all isolates was very constant. The fusiform and triradiate forms, which have been reported as being non-siliceous in the past, were found to have an amorphous particulate nature in TEM. These forms were examined using EDAX SEM elemental analysis and were found to contain silica in their cell walls.

**Key words:** diatom, brackish-water; diatom, morphology; Great Salt Lake, Utah; Phaeodactylum; Soap Lake, Washington.

The diatom *Phaeodactylum tricornutum* Bohlin (1897) was first described from coastal marine waters in Sweden in 1897. Since then it has been observed in other marine coastal waters, particularly in areas of high enrichment. Rushforth et al. (1988) gave the first report of this species occurring in inland waters after discovering the taxon in phytoplankton samples from Farmington Bay, Great Salt Lake, Utah. *Phaeodactylum*, a monotypic genus, differs from other diatom genera in that it produces several types of cells, one bearing a weakly silicified navicula-shaped diatom valve, the others reportedly lacking siliceous valves and having either a fusiform, triradiate, or rarely cruciform shape (Wilson and Lucas 1942, Wilson 1946, Bourelly and Dragesco 1955, Borowitzka and Volcani 1978). The typically single-celled diatom can occasionally form chains of variable length (Borowitzka et al. 1977). The long and confused taxonomic history of this peculiar species has been covered elsewhere (Hendey 1954, Rushforth et al. 1988).

Subsequent to observation of *Phaeodactylum* populations in Great Salt Lake, I isolated the taxon from Soap Lake, Grant County, Washington, an unusual alkaline lake in the arid western part of the state. Originally, I thought my isolate was a small *Navicula* in the *Navicula saprophila/permittis/pelliculosa* complex. However, after careful electron microscope analysis I realized that it was indeed a

*Phaeodactylum* species, although the alternate fusiform and triradiate cells have never been observed. I decided to undertake a comparative study of *Phaeodactylum* isolates to determine if morphological differences exist between marine and inland populations. This paper reports the results of that study.

METHODS

Five isolates of *P. tricornutum* were examined, all of which are maintained as part of the SERI Microalgae Culture Collection in Golden, Colorado. PHAEO1 (also designated TFX-1) was isolated from culture ponds at Woods Hole, Massachusetts, in September 1956 by Joyce and Ralph Lewin (Lewin et al. 1958). PHAEO2 (also designated BB) was isolated from coastal waters near Scripps Institution of Oceanography, La Jolla, California, by William H. Thomas (Barclay et al. 1986). PHAEO3 and PHAEO4 were isolated by myself from Farmington Bay, Great Salt Lake, Utah, 23 October 1986 and 26 March 1987, respectively. DIATO1 was isolated by myself from Soap Lake, Washington, 6 March 1987.

Marine isolates are routinely grown in GPM artificial seawater media, while inland strains are normally grown in SERI Type II/25 media (Barclay et al. 1986). However, all strains grow in SERI Type II/25. To eliminate morphological differences due to media differences, all cultures were grown in Type

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11/25 for one month prior to electron microscopical analysis.

*P. tricornutum* frustules are very fragile and are destroyed by boiling in nitric acid, a traditional diatom clearing procedure. To remove organic matter from the cultures, several techniques were employed, the best of which was to treat samples with concentrated  $H_2O_2$  for 12–24 hours, followed by heating in a boiling water bath to degrade unreduced  $H_2O_2$ . Samples were then cleared of soluble salts by repeated washing and centrifugation. Cleared samples were mounted in Naphrax resin for light microscope analysis. It should be noted that this method was gentle enough that even the valves traditionally considered unsilicified were not dissolved. Diluted cleared samples were also mounted on formvar coated hexagonal copper grids for transmission electron microscopy (TEM). Grids were examined on a JEOL 100CX transmission electron microscope at an operating voltage of 80 kV. Additional cleared material was mounted on carbon stubs, carbon coated by vacuum evaporation, and examined with an EDAX 9100 attached to a Hitachi HHS-2R scanning electron microscope (SEM) at an operating voltage of 20 kV.

## RESULTS

Simple elongated chloroplasts and circular lipid droplets are present in all cell types. In culture the naviculoid frustules produce more extracellular polysaccharides and form cohesive aggregates of cells that cannot be segregated by agitation. Fusiform and triradiate cells do not form cohesive aggregates. Naviculoid frustules were found in all five strains (Figs. 1, 5). Fusiform cells have been observed in PHAE01, PHAE02, PHAE03, PHAE04, and dominate cultures of PHAE01 and PHAE02 (Figs. 3, 4). During the past four years of culture history, triradiate cells have been observed only in PHAE03 and PHAE04, and they dominate cultures of those strains (Fig. 2). Chains like those recorded by Borowitzka et al. (1977) were seen rarely in cultures of PHAE01 and PHAE02.

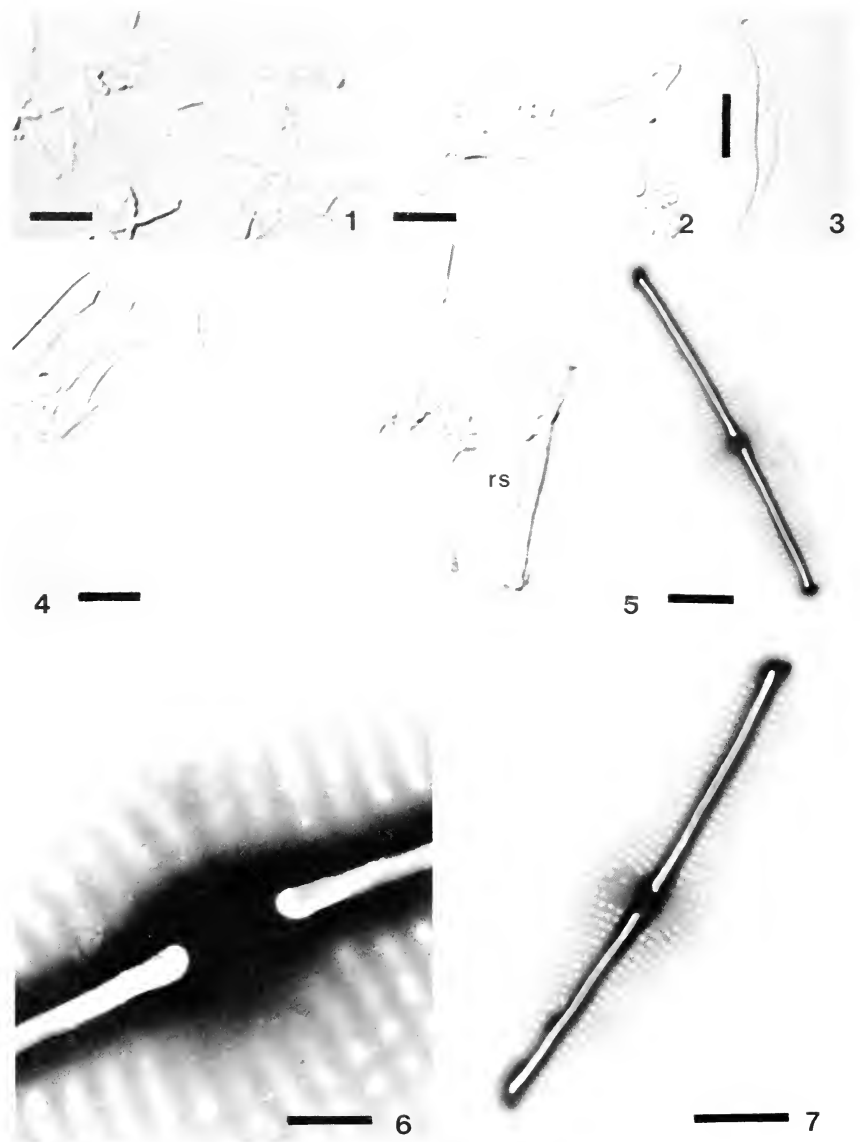
Since naviculoid frustules were observed in all strains, morphological comparisons based on these cells can be made. Valves of all strains have overlapping dimensions and are

morphologically indistinguishable. For this reason a summary of the traits of oval cells will be given without reference to strain. Cells are 7.5–16  $\mu\text{m}$  long by 2.5–6.5  $\mu\text{m}$  wide, with most cells 8–10  $\mu\text{m}$  by 3–4.5  $\mu\text{m}$ . The few larger cells were found in cultures of PHAE01 dominated by the fusiform cells and may represent transitional forms between the two forms. In living material, two types of naviculoid cells were observed, long thin cells and cells of similar length but greater width. Wilson (1946) also observed these cell types and noted that the thinner cells are characteristic of rapidly growing cultures, whereas the larger cells are more typical of nutrient-deficient conditions.

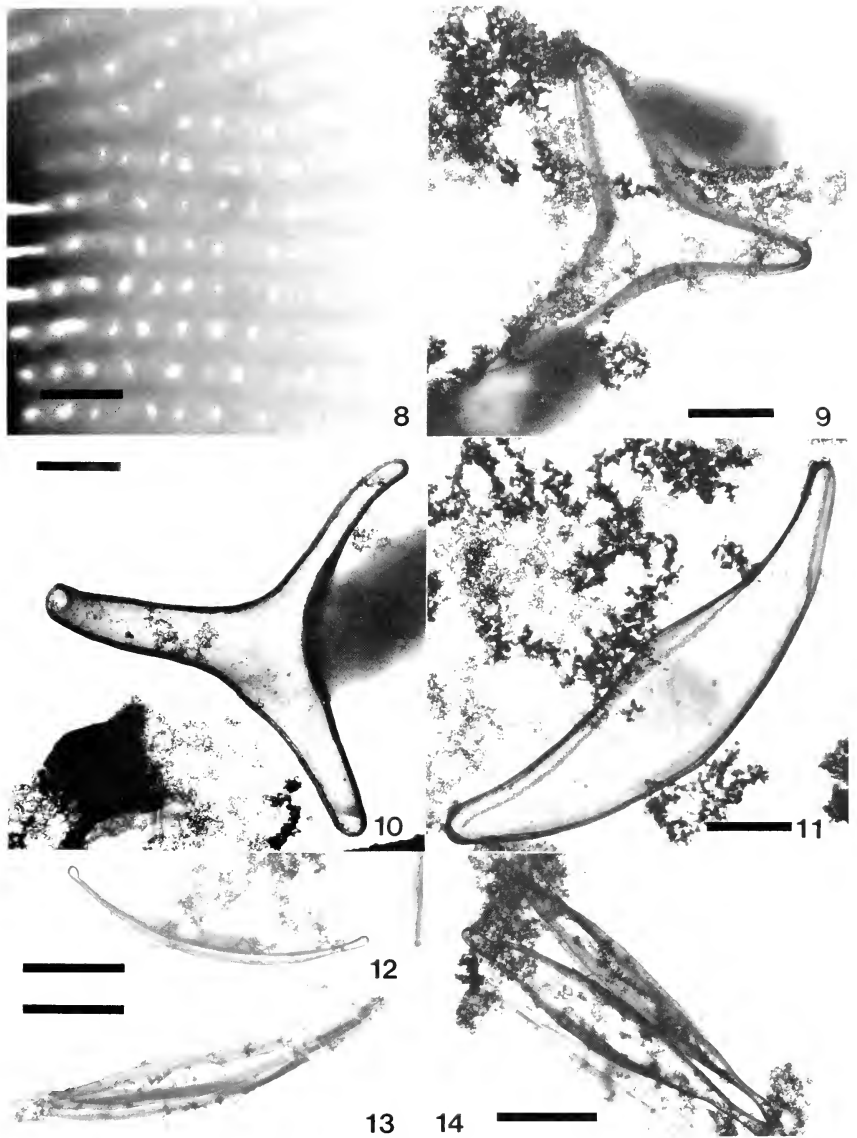
When naviculoid cells are cleared of organic matter, only the axial areas are distinguishable in light microscope mounts (Fig. 1). In TEM mounts, ultrastructure of the siliceous valve is revealed. Striae are usually parallel (Fig. 5), but they may be radiate (Fig. 7), especially around the central area (Figs. 6–8). Striae are evident as less thickly silicified areas of the valve that are perforated irregularly with simple pores (Figs. 5–8). Striae density ranges from 90 to 105 in 10  $\mu\text{m}$ . The axial area is thickly silicified, wider at the center, and flexed to one side, giving the valves a slightly assymetrical aspect. The central area is further set off from the rest of the valve by having "ghost striae" not perforated by pores in an orbicular region around the center of the axial area (Figs. 5–6). The raphe is distinctly lateral, becoming filiform at both distal and proximal ends. Proximal raphe ends are hooked consistently toward the dorsal margin (Fig. 6).

Triradiate cells were common in the isolates from the Great Salt Lake (PHAE03 and PHAE04). The forms figured in this paper (Fig. 2) have shorter arms than those from the cultures first isolated (see Rushforth et al. 1988, Figs. 2, 3). The length of the arms as measured from valve center to tip ranges from 6 to 15  $\mu\text{m}$ . In material cleared with hydrogen peroxide, the valve appears to be made of an amorphous particulate matrix and is clearly divided into valve face and mantle areas (Figs. 9, 10).

Fusiform cells are dominant in the marine isolates (PHAE01 and PHAE02). Cell dimensions are 15–27  $\mu\text{m}$  long by 3–5  $\mu\text{m}$  wide, dimensions similar to those reported by



Figs. 1–7. *Phaeodactylum tricornerutum*, cleared specimens: 1, naviculoid valves of DIATO1 showing axial areas; 2, triradiate cells of PHAEO4; 3, dorsiventrally arched fusiform cell from PHAEO4 cultures; 4, fusiform cells of PHAEO2 (note the highly refractive specimen [rs] in the lower right, which is apparently more heavily silicified than other cells in the micrograph [scale = 5  $\mu$ m for Figs. 1–4]); 5–7, DIATO1 naviculoid cells showing morphology of the striae, raphe, and central area (scales = 1  $\mu$ m, 0.2  $\mu$ m, and 1  $\mu$ m, respectively).



Figs. 8–14. *Phaeodactylum tricornerutum*, cleared specimens: 8, DIATO1 naviculoid valve showing details of striae ultrastructure (note irregular margin of the valve [scale = 0.2  $\mu$ m]); 9, 10, PHAE04 triradiate specimens showing amorphous particulate matrix of the valve (scale = 2  $\mu$ m); 11, tumid dorsiventrally arched fusiform cell of PHAE04 (scale = 2  $\mu$ m); 12, PHAE04; 13, PHAE02 striated girdle bands; 14, PHAE02 chain of cells showing striated girdle bands (scale = 5  $\mu$ m for Figs. 12–14).

Wilson (1946), but shorter than those reported by Lewin (1958). Many fusiform valves have a distinctly dorsiventral appearance (Fig. 3), cells which are thought to be transitional between fusiform and triradiate cells (Borowitzka and Volcani 1978). In TEM the valves appear to be composed of the same particulate matrix as the triradiate cells (Fig. 11). The ultrastructure of these walls has been covered in detail elsewhere. They consist of an external corrugated layer subtended by a thicker fibrillar layer embedded in an amorphous matrix (Reimann and Volcani 1968, Borowitzka and Volcani 1978). All of these wall components have been assumed to be completely organic. Valve face and mantle regions are evident (Figs. 11, 12). The cingulum consists of a single siliceous striated band (Figs. 13, 14), which has been examined in detail elsewhere (Neuville et al. 1971, Borowitzka and Volcani 1978).

In cleared material some fusiform frustules appeared more refractive than others (Fig. 4). These cells had the appearance of having silica in their valves, even though previous workers reported that fusiform cell walls were unsilicified (Lewin 1958, Lewin et al. 1958, Borowitzka and Volcani 1978). In light of this finding, elemental analysis of cleared cell walls of cells grown in silica-deficient media was undertaken. The EDAX readout indicated the presence of silica, as well as smaller amounts of Na, Mg, Al, P, S, and Ca (Fig. 15).

#### DISCUSSION

The morphological observations on inland and marine strains of *Phaeodactylum tricornutum* presented in this paper agree with the observations made by others (Wilson 1946, Lewin et al. 1958, Reimann and Volcani 1968, Borowitzka et al. 1977, Borowitzka and Volcani 1978). The inland strains did not differ morphologically from the marine strains. It is interesting to note that the Great Salt Lake strains were typically triradiate, the Soap Lake form produced only oval cells, and the marine forms were typically fusiform. However, given the past history of this species in culture (Wilson 1946), little significance can be attached to such differences.

External mucilaginous polysaccharides were associated only with oval cells, in agreement with the observations of Lewin et al. (1958).

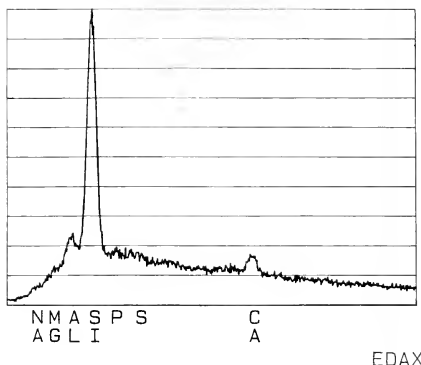


Fig. 15. EDAX elemental analysis of fusiform cell of *Phaeodactylum tricornutum*. Note the strong silica peak.

The ability of oval cells to grow on agar, the absence of mucilage from triradiate and fusiform cells, and the higher buoyancy of triradiate and fusiform cells suggest that the oval form is benthic, while the other forms are planktonic (Round et al. 1990). One wonders if in a small inland lake such as Soap Lake there is less opportunity for planktonic forms, and hence the dominance of the oval form.

By far the most surprising observation in this paper is the presence of silica in the cell walls of the fusiform and triradiate cells. Because this finding contradicted the assumptions of other workers, a number of valves were studied with EDAX elemental analysis. Care was taken to focus the beam on a very small region in the center of the valve to avoid picking up a silica signal from the siliceous bands. Lewin et al. (1958) reported the presence of flocculent, structureless silica following nitric acid digestion of fusiform cells. They assumed that the silica was from internal reserves, not from walls. Reimann and Volcani (1968) and Borowitzka and Volcani (1978) presented high-resolution TEM micrographs of the cell walls of *Phaeodactylum* fusiform cells. From examination of these micrographs, it seems possible that the fibrillar electron-dense layer of the wall may contain silica embedded in an organic matrix. Alternatively, silica may be present in some amorphous form. Since the silica is not organized into a solid siliceous structure as in other diatoms, it has been disregarded as a component of the

walls, which have been falsely assumed to be totally organic.

It appears that silica is present to varying degrees within fusiform and triradiate cells (Fig. 4). The cultures in this study, routinely grown with fairly high available silica, were transferred to silica-free medium only a few days before analysis. It may be that others (Reimann and Volcani 1968, Borowitzka and Volcani 1978) have used low-silica media and thus not favored facultative silica deposition in fusiform and triradiate cells.

As this enigmatic and peculiar diatom continues to be found in new localities, it will probably continue to draw the interest of phycologists. It seems very possible that the taxon is widely distributed in inland saline water and has avoided detection because the cell walls tend to be destroyed in standard diatom preparation procedures.

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## VEGETATION AND SOIL ZONATION ASSOCIATED WITH *JUNIPERUS PINCHOTII* SUDW. TREES

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**ABSTRACT.**—Herbaceous vegetation pattern and soil properties around individual *Juniperus pinchotii* Sudw. trees were studied on a grazed and a relict grassland in western Texas. Herb standing crop and soil samples were obtained under the canopy, at canopy edge, and beyond the canopy edge of three to five trees on each of four dates. Standing crop was lowest midway between the bole and canopy edge. Soil organic matter was highest under juniper canopies on both sites. Soil pH and P were not related to distance from tree bole on either site. Herbaceous pattern from under the canopy to canopy edge apparently depended primarily on individual tree size. However, trees had little influence on herbaceous vegetation pattern 3–5 m beyond canopy edge, a response attributed to distance-independent interaction between *J. pinchotii* and herbaceous vegetation. Given a shallow soil underlain by indurated caliche and tree densities ranging from 288 (relict site) to 2123 (grazed site) trees/ha, the interaction between *J. pinchotii* and herbaceous vegetation did not change over a distance of 3–5 m from tree canopy edge in our study area.

**Key words:** *Juniperus pinchotii*, redberry juniper, vegetation pattern, soil nutrients, herbivory, relic area, competition.

Zones of herbaceous vegetation around *Juniperus* trees have been reported for several species in the western United States (Arnold 1964, Clary 1973, Springfield 1976, Everett et al. 1983, Schott and Pieper 1985). The most commonly recognized vegetation zones are: (1) under woody plant canopies, where *Juniperus* litter and shade alter micro-environment; (2) in a transition zone, where *Juniperus* roots compete with herbaceous plants for water and nutrients; and (3) in the interstice between trees, where trees do not influence herbaceous vegetation. In contrast, a zonation pattern was not detected around *J. virginiana* in Oklahoma (Engle et al. 1987) or *J. monosperma* in New Mexico (Armentrout and Pieper 1988). In these studies, herbaceous vegetation beyond tree canopies did not change with increased distance from trees.

Woody species influence soil properties primarily by rooting and litterfall characteristics (Barth 1980). Chemical constituents from surrounding soil are taken up by tree roots and concentrated in biomass. Litterfall transfers much of this biomass to the area beneath the canopy where it accumulates, and decomposition releases chemical constituents to

the underlying soil. Soluble salts (Fireman and Hayward 1952, Sharina and Tongway 1973), nitrogen and phosphorus (reviewed by Tiedemann 1987), and zinc, iron, and magnesium (Hibbard 1940, Follett 1969, Barth 1980) have been implicated in this process.

*Juniperus pinchotii* Sudw. (nomenclature follows Correll and Johnston 1970), a sprouting evergreen conifer commonly found on limestone or gypseous soils, occupies about 2.4 million ha of rangeland in western and central Texas (Adams 1972). Throughout its range, *J. pinchotii* migrated quickly onto prairies during the expansion of the cattle industry (1870–1920) (Hall and Carr 1968, Adams 1975). Western Texas populations of *J. pinchotii* previously restricted to buttes and escarpments have subsequently expanded into adjacent grasslands and have become a major vegetation component (Ellis and Schuster 1968). The primary objective of this study was to determine the effects of individual *Juniperus pinchotii* trees on herbaceous vegetation and soil properties at a grazed and a relict site in western Texas.

### STUDY AREAS

Two western Texas study sites were used.

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Flattop Mountain, an isolated butte 11 km northwest of Snyder (101°10'W, 33°00'N), has not been grazed by livestock but is accessible to wildlife species and supports relict vegetation (McPherson 1987). Nine km southeast of the butte is an area with considerable historic grazing pressure. The grazed site is contiguous with the Llano Estacado High Plains; the relict site is a High Plains outlier (Brown and Schuster 1969). Average annual precipitation is 472 mm (Dixon 1975). Dominant soil on both sites is a shallow (about 50 cm) clay loam of the Lea-Slaughter complex (fine-loamy, mixed, thermic Petrocalcic Paleustolls and clayey, mixed, thermic, shallow Petrocalcic Paleustolls) (Dixon et al. 1973, Dixon 1975). These sites represent environmental settings whose primary extrinsic difference is domestic livestock grazing. The sites may also have intrinsic soil differences.

#### METHODS

On each site, 20 *Juniperus* plants were selected randomly, except for the requirements that they were (1) beyond the shading influence of other junipers; (2) between 1.0 and 4.0 m tall; and (3) at least 5 m from roads, shallow soil (gravel present at surface), or visibly disturbed areas. Standing crop of herbaceous vegetation was estimated around three to five randomly selected trees on each site in July (corresponding to peak standing crop) and October (to assess autumn productivity) 1984 and 1985, years in which study sites received 42 and 96% of long-term growing season precipitation (420 mm), respectively (McPherson 1987). Transects were established in the cardinal directions from the stem, ending 3 m beyond the canopy edge. Rectangular quadrats (0.10 m<sup>2</sup>) were located at midpoint between canopy edge and stem (location 1), at canopy edge (location 2), and at 1.0-m intervals beyond the canopy edge (locations 3–5). Two quadrats were randomly located along each of 10 randomly located 5-m permanent transects in the interstice between trees (at least 5 m from nearest *Juniperus* plant; location 1). Standing crop in quadrats was harvested to a 2.5-cm stubble height and separated by species. Herbage samples were oven-dried at 60 C for 48 h and weighed.

Two complete soil horizons were exposed and profiles described to the depth of indurated caliche on each site (McPherson 1987).

Soil samples were collected from the 0–10-cm soil layer halfway between bole and canopy edge, at canopy edge, and at 1, 2, and 3 m along a southward transect from five randomly selected trees on each site in May 1986. Determination of calcium carbonate equivalent followed Richards (1954); organic matter content (OM) was determined by wet digestion (Prince 1955). Samples were analyzed for nitrogen (N), potassium (K), phosphorus (P), exchangeable calcium (Ca), sodium (Na), and magnesium (Mg) following Onken et al. (1980). Soluble salt and pH determination followed McLean (1982).

Species occurring with less than 5% frequency on all sites and dates were removed from the data set (Gauch 1982), leaving 57 species for subsequent analyses. Standing crop values were log transformed (Steel and Torrie 1980). Analysis of variance, Fisher's protected LSD, and reciprocal averaging ordination (RA) were used to analyze the effect of *Juniperus* trees on herbaceous vegetation and soil properties. Variability from tree to tree was taken into account by considering trees as blocks in a randomized complete block design in the analysis of variance. The "treatment effect" in this analysis was quadrat distance from tree bole.

#### RESULTS

##### Herbaceous Vegetation

Strong interactions ( $P < .01$ ) between tree (block) and quadrat distance from tree (treatment) were exhibited by 56 of 57 species on all dates and sites (a tree  $\times$  distance interaction was not present [ $P > .05$ ] for *Bouteloua curtipendula* [Michx.] Torr. on the relict site on any date). Tree  $\times$  distance interactions were also exhibited by plant guilds (cool-season grasses, warm-season grasses, forbs) and for total standing crop.

With only one grazed site and one relict site, it is not possible to statistically test the effect of site. Within a site, apparent differences in aboveground biomass between years (Table 1) were attributable to differences in precipitation (about twice as great in 1985 as 1984). (For elaboration of site and year effects on herbaceous production, see McPherson and Wright 1990.) However, vegetation composition within each site was similar on all sampling dates (Table 1). Ordination results

TABLE 1. Standing crop (g/m<sup>2</sup>) of selected herbaceous species on grazed and relict grassland at six locations around *Juniperus pinchotii* trees in western Texas, July and October 1984 and 1985 (each number is mean of four cardinal directions and three to five trees).

Species <sup>1</sup>	GRAZED SITE											
	July 1984						October 1984					
	Location <sup>2</sup>						Location					
	1	2	3	4	5	1	1	2	3	4	5	1
GRASSES												
ARSP	0	6	90	192	173	270	0	401	125	113	124	156
BOCU	6	29	24	193	16	23	0	141	107	38	63	53
BUDA	0	2	4	2	2	6	0	6	4	6	6	5
TRMU	0	2	6	58	4	34	0	72	24	61	64	52
STNE	121	61	0	0	0	0	0	0	0	0	0	0
SIHY	0	11	0	0	0	0	70	0	0	0	0	0
Other grasses	2	13	4	10	6	15	0	122	46	57	60	27
FORBS												
CRDI	0	0	2	20	51	98	0	37	111	73	96	80
SICA	8	28	0	0	0	0	146	0	11	158	0	6
ZIGR	0	4	2	24	2	39	12	60	12	7	13	65
EVNU	0	4	17	34	8	43	0	8	15	21	27	30
LEER	0	0	37	2	6	14	0	2	8	2	0	23
CADR	0	4	6	6	4	8	2	11	6	38	63	37
ERMO	0	0	0	0	0	0	0	0	0	0	0	0
Other forbs	71	94	96	139	120	149	16	126	99	98	276	158
TOTAL	208	258	288	680	392	699	246	986	568	672	792	692
RELICT SITE												
GRASSES												
ARSP	0	2	2	161	73	113	0	4	0	4	0	52
BOCU	248	217	436	285	333	830	26	116	157	95	122	184
BUDA	0	2	14	23	15	18	0	8	2	0	2	0
TRMU	0	13	25	19	0	60	0	42	0	19	22	30
STNE	123	19	13	0	0	0	0	0	0	34	0	39
SIHY	0	0	0	0	0	0	62	7	0	0	0	0
Other grasses	56	155	59	171	2	82	8	120	156	107	59	31
FORBS												
CRDI	0	0	0	0	0	0	0	0	0	0	0	0
SICA	6	0	0	0	0	0	30	2	0	0	20	5
ZIGR	0	0	0	0	0	0	0	0	0	0	0	0
EVNU	0	0	0	0	6	0	0	0	0	0	0	0
LEER	0	0	0	0	0	0	0	0	0	0	0	0
CADR	0	0	0	0	0	0	0	0	0	0	0	0
ERMO	0	0	0	0	0	0	0	0	0	0	0	0
Other forbs	13	10	13	25	75	62	8	26	25	19	24	49
TOTAL	446	418	562	684	504	1165	134	325	340	278	249	390

were also similar on each sampling date. Because ordination diagrams, which included all sampling dates, contained too many points to plot adequately, only results from the October 1985 sampling date are shown.

Effects of *J. pinchotii* on herbaceous vegetation pattern were recognizable at several

scales (landscape, community, and individual tree). Evaluation of pattern at the landscape level involved ordinating all trees on both sites (Fig. 1). The first ordination axis indicates a site effect: all quadrats from the relict site were assigned negative first axis scores, and most quadrats from the grazed site were

TABLE 1 continued. Data for 1985.

Species <sup>1</sup>	GRAZED SITE											
	July 1985						October 1985					
	Location						Location					
	1	2	3	4	5	1	1	2	3	4	5	1
GRASSES												
ARSP	2	61	393	586	347	570	0	16	64	211	188	228
BOCU	114	198	19	27	49	186	8	79	0	0	0	209
BUDA	0	12	18	13	19	41	17	8	8	7	22	7
TRMU	8	118	50	54	83	127	4	114	34	85	172	181
STNE	0	0	0	0	0	0	0	0	0	0	0	0
SHY	120	2	0	0	0	0	126	0	0	0	0	0
Other grasses	0	114	38	134	118	80	2	187	82	184	204	13
FORBS												
CRDI	0	109	190	145	230	127	0	50	131	68	118	30
SICA	390	2	0	0	13	0	0	4	0	0	0	0
ZIGR	0	65	0	0	0	94	0	36	119	53	31	48
EVNU	0	13	38	24	71	100	0	24	34	65	33	45
LEER	14	37	132	83	101	82	169	476	436	152	212	20
CADR	8	12	26	43	127	57	0	44	20	7	133	43
ERMIO	10	312	79	36	13	46	57	57	90	63	85	67
Other forbs	145	185	292	273	211	474	77	174	150	158	134	184
TOTAL	811	1240	1275	1418	1382	1984	460	1269	1168	1053	1332	1075
RELICT SITE												
GRASSES												
ARSP	0	107	135	83	183	88	0	16	21	7	113	254
BOCU	0	463	417	351	379	595	91	356	609	615	830	605
BUDA	0	45	35	55	44	26	5	15	8	11	18	45
TRMU	0	47	46	42	33	2	57	274	43	54	60	23
STNE	25	796	247	186	277	25	0	0	0	0	0	10
SHY	245	117	57	0	0	27	252	66	1	0	0	0
Other grasses	0	74	106	54	64	173	38	280	177	226	82	162
FORBS												
CRDI	0	0	2	0	0	0	0	0	0	0	0	0
SICA	131	145	41	16	0	9	3	39	3	0	0	3
ZIGR	0	0	0	0	0	0	0	0	0	0	0	0
EVNU	0	0	0	0	3	0	0	0	0	0	0	0
LEER	0	0	0	0	0	0	0	0	0	0	0	0
CADR	0	0	0	0	0	0	0	6	2	0	0	0
ERMIO	191	123	74	138	84	134	223	180	117	42	111	139
Other forbs	53	91	255	139	349	186	50	52	43	79	69	35
TOTAL	645	2008	1415	1064	1416	1265	719	1284	1024	1034	1283	1276

<sup>1</sup>Species abbreviations are: ARSP = *Aristida* sp., BOCU = *Bouteloua curtipendula*, BUDA = *Buchloe dactyloides*, TRMU = *Tridens nutans*, STNE = *Stipa neomexicana*, SHY = *Sitanion hystrix*, CRDI = *Croton dioecis*, SICA = *Simsia calva*, ZIGR = *Zinnia grandiflora*, EVNU = *Ecolulus nuttallianus*, CADR = *Calypophus drummondianus*, ERMIO = *Erigeron modestus*.

<sup>2</sup>Locations are midway between tree bole and dripline (1), at dripline (2), 1, 2, and 3 m from dripline (3–5, respectively), and in interstices (1).

assigned positive first axis scores. Exceptions were quadrats under tree canopies (location 1 and, to a limited extent, location 2) on the grazed site.

Ordination of quadrats along the second axis (Fig. 1) indicates a gradient from tree bole

to interstice representing tree influence on herbaceous vegetation. Location 1 quadrats (under the tree canopy) were ordinated together, as were quadrats beyond the canopy edge (locations 3–5, 1). Quadrats at the canopy edge (location 2) were ordinated

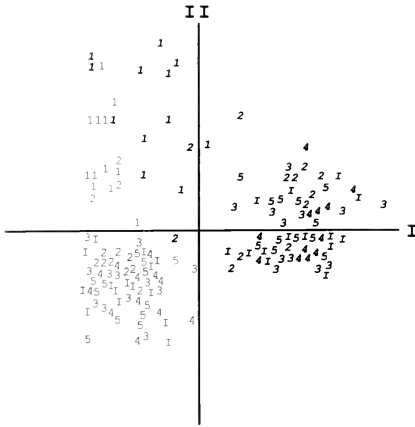


Fig. 1. Reciprocal averaging quadrat ordination around *Juniperus pinchotii* Sudw. trees on grazed (bold type) and relict (normal type) semiarid grasslands. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively. Location 1 is in interstice between trees.

between quadrats under the tree and those beyond the canopy edge.

Ordination of all trees on the relict site (Fig. 2) and the grazed site (Fig. 3) reflects community-level analyses. On both sites, axis I reflected a distance gradient from tree bole to interstice. Quadrats under the canopy and at canopy edge were assigned negative first axis ordination scores, whereas other quadrat locations were generally assigned positive scores. Additionally, quadrats at locations 3–5 were ordinated together with quadrats from the interstitial zone. Axis II reflected tree-to-tree variation. Small trees (height, stem diameter, and crown volume) were ordinated more positively on this axis than were large trees (data not shown). Ordinations did not indicate any effect of compass direction on herb response.

Ordination of a single tree on each site further elucidated the tree's influence on herbaceous vegetation beneath the canopy (Figs. 4, 5; in each case, axis III was plotted against axis I to reduce arch distortion associated with the plot of axes I and II). The ordination revealed that quadrats under the tree (location 1) were readily distinguishable from remaining quadrats. Quadrats 1, 2, and 3 m

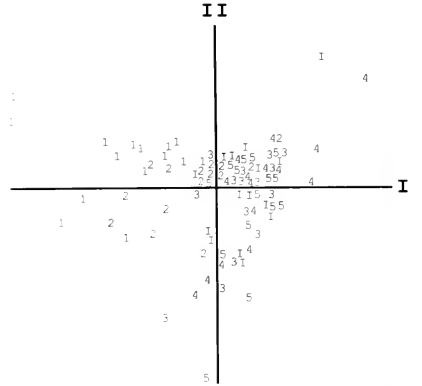


Fig. 2. Reciprocal averaging quadrat ordination around *Juniperus pinchotii* Sudw. trees on a relict semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively. Location 1 is in interstice between trees.

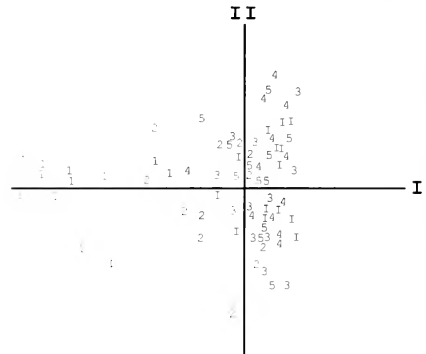


Fig. 3. Reciprocal averaging quadrat ordination around *Juniperus pinchotii* Sudw. trees on a grazed semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively. Location 1 is in interstice between trees.

from the tree (locations 3, 4, and 5) tended to be ordinated together. Quadrats at canopy edge (location 2) were assigned ordination scores intermediate between these two groups.

### Soil Properties

Organic matter, soil P, and pH differed ( $P < .05$ ) between sites; however, trees influenced few of the measured soil properties.

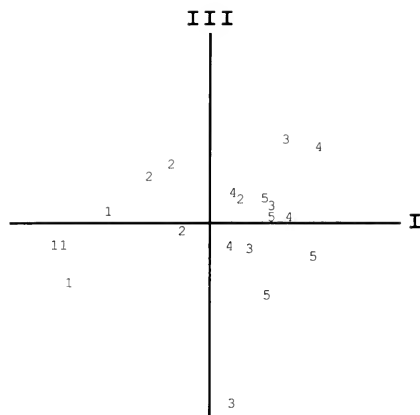


Fig. 4. Reciprocal averaging ordination around a *Juniperus pinchotii* Sudw. tree on a relict semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively.

Organic matter was higher ( $P < .05$ ) under trees than at or beyond canopy edge on both sites (Table 2). Potassium and salinity were slightly higher at the edge of the canopy than at other locations on the relict site. Other soil properties were unaffected by distance from tree bole.

#### DISCUSSION

These data indicate that site differences reflecting differences in environment and possibly grazing history had a relatively large impact on soils and herbaceous vegetation. Although parent material and physical environment appeared similar for the two sites, these sites may have differed with respect to localized precipitation patterns or geochemical processes. It is also noteworthy that these two study areas have different histories with respect to livestock grazing. Livestock grazing can influence these soil properties (Whitehead 1970, Kleiner and Harper 1972, Bauer et al. 1987).

Our data indicate that *J. pinchotii* trees had minimal impact on most soil properties, results which differ markedly from those reported for *Juniperus* species in the western U.S. (for a review see Tiedemann 1987). For example, Barth (1980), Thran and Everett

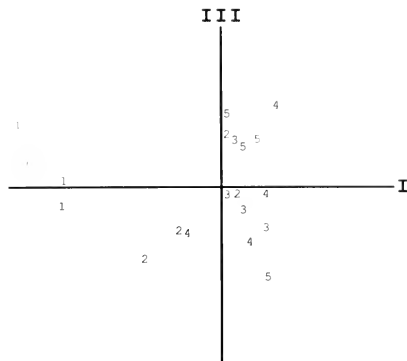


Fig. 5. Reciprocal averaging ordination around a *Juniperus pinchotii* Sudw. tree on a grazed semiarid grassland. Location 1 is at midpoint between tree bole and canopy edge; location 2 is at canopy edge; and locations 3, 4, and 5 are 1, 2, and 3 m from canopy edge, respectively.

(1987), and Klopatek (1987) found 1.5–5.5 times more soil N under pinyon or juniper trees than in interstices. Concentrations of soil P, K, Mg, Ca, and Na followed similar patterns. However, Brotherson and Osayande (1980) reported no differences in P or cations and only a slight difference in N (0.049 vs. 0.044%) under *J. osteosperma* trees and in open areas. Mean soil N was 0.015% in our study area, which is probably growth-limiting. Tiedemann (1987) indicated that 0.05–0.5% total N is sufficient for grassland and shrubland soils. Differences in soil organic matter at different distances from the bole probably resulted from deposition and subsequent decomposition of *Juniperus* foliage.

Herbs in location 1 and, to a lesser extent, location 2, were protected from grazing by *Juniperus* trees. *Juniperus pinchotii* is a closed-canopy species that does not self-prune lower branches. This growth form offers protection from grazing under canopies. At each site, *J. pinchotii* had little influence on herbaceous vegetation or soil properties beyond the tree crown. Our results indicate less tree influence on herbaceous vegetation than commonly reported for *Juniperus* species in the western U.S. That there was no discernible pattern in herbaceous vegetation 1–3 m past the tree canopy and beyond into the interstitial zone does

TABLE 2. Soil properties of grazed and relict grassland at five locations around *Juniperus pinchotii* trees in western Texas.

Soil property	Site <sup>2</sup>	Location <sup>1</sup>				
		1	2	3	4	5
OM (%)	R	4.2aA <sup>3</sup>	3.4b	3.3bA	3.4bA	3.4bA
	G	3.5aB	2.9b	2.5cB	2.5cB	2.5cB
K (ppm)	R	490.0b	568.0a	437.0b	435.0b	460.0b
	G	461.0	593.0	494.0	451.0	661.0
Salinity (ppm)	R	358.0ab	374.0a	318.0b	325.0b	342.0b
	G	315.0	329.0	297.0	310.0	316.0
P (ppm)	R	6.5A	7.0A	6.2A	7.8A	7.5A
	G	19.9B	17.3B	18.3B	17.7B	17.1B
pH	R	8.0	7.8A	7.9A	7.8	7.9A
	G	8.0	8.2B	8.1B	8.0	8.1B

<sup>1</sup>Locations are midway between tree hole and dripline (1), at dripline (2), and 1, 2, and 3 m from dripline (3, 4, and 5, respectively).  
<sup>2</sup>R = relict site, G = grazed site.  
<sup>3</sup>Means within a row followed by the same lowercase letter are not significantly different ( $P > .05$ ) according to Fisher's protected LSD. Means within a column for each soil property followed by the same uppercase letter are not significantly different ( $P > .05$ ) according to Fisher's protected LSD.

not imply that herbaceous vegetation has not reacted to the presence of *J. pinchotii* trees, but rather that this response is distance-independent. That is, it is likely that interaction between *J. pinchotii* and herbaceous vegetation is similar 1 m from the tree canopy and 5 m beyond the tree canopy. Personal observations of mechanically uprooted *J. pinchotii* trees have revealed that the root system of these trees is laterally extensive. Furthermore, soils of our study areas were less than 50 cm deep and were underlain by indurated caliche (McPherson et al. 1988); these conditions are conducive to lateral root growth. Plummer (1958) and Arnold (1964) also reported *Juniperus* roots in openings between trees, and Johnsen (1962) found many juniper roots up to 16 m from trees. Lateral roots in the latter study commonly exceeded tree heights by threefold. Therefore, the concept of "interstitial zone" may have meaning only in an "aboveground" sense in our study area (where average juniper density is 2123 trees/ha on the grazed site and 288 trees/ha on the relict site [McPherson et al. 1988]). At these tree densities, there may be no zone underground where root occupancy between *J. pinchotii* and herbaceous vegetation is minimal. This interpretation is supported by *J. pinchotii* trees in our study area ranging in age from less than 10 yr to 120 yr old (McPherson 1987). Although *J. pinchotii* is increasing in density in the area, it is not a recent invader of the site, and the older, larger trees are well established and are assumed to have extensive lateral root systems.

The presence of tree- $\times$ -quadrat location interaction in our study is of considerable interpretational importance. This interaction indicates that the response of most herbs to distance from *J. pinchotii* depends upon particular characteristics of the tree in question, and precludes general statements about herbaceous pattern related to distance from *J. pinchotii* plants. Contrary to most other studies, we found little discernible zonation beyond the tree canopy. We attribute this interaction to the effect of tree size on vegetation *immediately* beneath the tree (our trees ranged from 1 to 4 m tall). This zone increases with increasing tree size, so that the variation in herbaceous vegetation between locations 1 (midway between tree bole and canopy edge) and 2 (at canopy edge) is strongly influenced by tree size (see Schott and Pieper [1985] for a detailed study on the effect of tree size/age characteristics on resulting subcanopy microenvironment and vegetation). The importance of differences in microclimate associated with compass directions (Arnold 1964, Everett et al. 1983, Armentrout and Pieper 1988) apparently was masked by other factors in our study.

Existence of herbaceous zonation patterns beyond the tree canopy depends upon species and age of *Juniperus* involved, composition of surrounding herbaceous vegetation, and environment (Arnold 1964, Everett et al. 1983, Engle et al. 1987, Armentrout and Pieper 1988). In arid and semiarid environments there is often a reduction in intensity of competition with improvement of soil water status

(see Fowler [1986] for a review). We suggest that herbaceous zonation beyond the tree canopy is more likely to develop around western junipers in drier environments (e.g., *J. osteosperma* in Everett et al. 1983) than around eastern junipers in more mesic environments (e.g., *J. virginiana* in Engle et al. 1987) because limiting moisture in the former setting intensifies species interactions. Superimposed on this "environmental" effect is the influence of herbaceous species composition (e.g., Armentrout and Pieper 1988). This interpretation is consistent with the observation that *J. pinchotii* is a stabilized hybrid between two western junipers (*J. deppeana* and *J. monosperma*) (Hall 1963, Hall and Carr 1968, Adams 1972, 1975) which, by virtue of its increasing density in western and central Texas grasslands, is evidently well adapted to a moisture regime more favorable than that experienced by its progenitors.

It is noteworthy that effects of *J. pinchotii* on herbaceous vegetation pattern were recognizable at several scales (landscape, community, and individual tree). Arnold (1964) first described herbaceous vegetation patterns around *Juniperus* using a single tree. Subsequent research (e.g., Clary 1973, Springfield 1976, Everett et al. 1983, Schott and Pieper 1985) increased the sample size but still focused on the impact of individual trees on herbaceous vegetation patterns. Our study indicates that patterns detectable at the level of individual trees may also be identified at much larger scales.

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## TWO NEW SPECIES OF *AUREALCAULIS* (OSMUNDACEAE) FROM NORTHWESTERN NEW MEXICO

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**ABSTRACT.**—Two new osmundaceous species, *Aurealcaulis moorei* and *A. bransonii*, are described from the San Juan Basin of northwestern New Mexico. The area from which they were collected is uncertain, but it is presumed they came from the Lower Eocene San Jose Formation near Angel Peak, southeast of Bloomfield, New Mexico. The species are characterized by having a heterogeneous (*A. moorei*) to homogeneous (*A. bransonii*) pith, non- or partial closure of their leaf gaps, exarch protoxylem clusters, formation of their C-shaped leaf traces by fusion of two segments from adjacent xylem strands in their inner cortices, relatively low numbers of traces in their cortices (16–22 in *A. moorei*, 15–19 in *A. bransonii*), roots arising from lateral margins of these segments, sclerenchymatous outer cortex that connects with the sclerotic ring of the petiolar vascular strand, crenate (*A. moorei*) or interrupted (*A. bransonii*) sclerenchyma lining the adaxial concavity of their petiole strands, and leaf bases that may or may not contain one, occasionally two, sclerotic cellular masses in their stipular wings in *A. moorei* and 6–8 more or less aligned masses in *A. bransonii*. They are compared with other osmundaceous taxa, particularly *A. crossii* Tidwell & Parker of Paleocene age. Because of variations in these new species, *Aurealcaulis* Tidwell & Parker is slightly emended to accept species of this genus with heterogeneous or homogeneous piths, protoxylem becoming endarch in the leaf traces, petiolar vascular strands formed by fusion of segments from the xylem strands in the inner cortex, outer cortex, or outside the stem, and the occurrence or nonoccurrence of sclerenchyma in the adaxial concavity of their petiolar vascular strands and in their stipular wings. The paleoecological conditions under which these species of *Aurealcaulis* grew are also considered.

**Key words:** *Aurealcaulis*, *Osmundaceae*, New Mexico, Eocene, San Juan Basin, San Jose Formation.

*Aurealcaulis* Tidwell & Parker (1987) has a rather limited fossil record at present, but with the addition of the two new species described in this report from the San Juan Basin, New Mexico, and a third as yet unreported one from near the Black Hills, South Dakota, it seems to have been an important, albeit small, component of Early Tertiary floras. The genus also appears to have possibly occurred higher in the Tertiary before it became extinct and was more widely distributed than previously known.

The definite age and collection site for the specimens upon which this paper is based are currently unknown. Portions of them were donated first by Mr. Doug Moore of Glendora, California, who assumed they were collected from the Upper Jurassic Morrison Formation in Lisbon Valley of east central Utah (Tidwell et al. 1989). Mr. William Branson of Helper, Utah, from whom Mr. Moore had originally obtained the specimens, corrected this information and stated he had in turn

acquired them from Mr. J. B. Sanchez of San Juan Gems of Cortez, Colorado. An unknown collector had sold them to Mr. Sanchez, and the only information he had was that they were collected near Farmington, New Mexico, and had been purchased with fossil wood preserved as bright yellow jasper. The fossil wood was traced to the Upper Cretaceous Kirtland Shale northwest of Farmington, but the ferns were never found. The ferns, however, are anatomically more advanced than *Aurealcaulis crossii* of Paleocene age and therefore are most likely from the Lower Eocene San Jose Formation, presumably from an area east of Angel Peak, southeast of Bloomfield, New Mexico. Considerable time and money have been spent attempting to locate the site, but the effort as yet has been unsuccessful.

Reports of fossil plants in the stratigraphic units from the Angel Peak region are rather sparse. Numerous fossil vertebrates, however, have been described from the Paleocene

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Nacimiento Formation on the west side of the peak (Wilson 1951, Taylor 1981). Although abundant undescribed fossil woods occur in the San Jose Formation, the only fossil plants previously recorded from the formation in this general area are compressional-impressional material from nearby Santos Peak (Tidwell et al. 1981). This small flora of leaves and leafy shoots consists of 15 species representing ferns, conifers, and flowering plants. The ferns include fragments of the leaves of *Acrostichum hesperium* and specimens of probable *Danaea*.

This report of *Aurealcaulis* species from New Mexico is significant because they are the first permineralized specimens of Osmundaceae and only the second report of osmundaceous fossils from this state. Leaves assignable to *Cladophlebis* sp. and *Osmunda hollicki* Knowlton were previously reported from the Upper Cretaceous Fruitland-Kirkland Formations in the San Juan Basin (Tidwell et al. 1981). Knowlton (1917) described *O. hollicki* from the Upper Cretaceous Vermejo Formation across the border near Wallburg, Colorado, and the senior author collected osmundaceous leaves, but did not report them, from a coal mine in the Paleocene Raton Formation west of Raton, New Mexico.

#### TAXONOMY

##### *Aurealcaulis* Tidwell & Parker, emended

EMENDED DIAGNOSIS.—Fossil osmundaceous rhizomes, arborescent or erect axes, surrounded by a mantle of leaf bases and adventitious roots; dissected ectophloic siphonostele or ectophloic dictyostele; xylem cylinder 10 or more tracheids thick, high number xylem strands, leaf gaps delayed, high, and wide; pith homogeneous or heterogeneous; cortex differentiated into inner and outer tissues; leaf traces often found in two segments, adaxially curved, protoxylem exarch, fusing and becoming endarch in inner cortex, outer cortex, or outside stem; petioles stipulate; sclerenchyma lining petiolar vascular strands may or may not be present; sclerotic ring homogeneous; stipular wings with or without sclerenchyma; roots diverge from leaf traces in inner cortex.

##### *Aurealcaulis moorei*, sp. nov.

Figs. 1A-B, 2, 3A

DIAGNOSIS.—Erect or arborescent, stem 14–16 mm in diameter, surrounded by leaf bases and roots; stele 7–8 mm across, dissected ectophloic siphonostele; pith 2–2.5 mm across, heterogeneous; xylem cylinder dissected, 32–36 xylem strands separated by leaf gaps, strands 15–18 tracheids thick radially, gaps lack closure, protoxylem exarch; phloem external; inner cortex 0.7–1 mm wide, parenchymatous; outer cortex homogeneous, 2–3 mm wide, sclerenchymatous; 16–22 leaf traces per transverse section of cortex; departing leaf trace two segments originating from adjacent xylem strands, fused into C-shaped trace in inner cortex; protoxylem becoming endarch, petiolar vascular strand curved, sclerotic tissue adaxially flattened, becoming crenate; sclerotic ring homogeneous, sclerenchymatous; stipular wings may or may not contain one, occasionally two, large, round cellular masses of sclerenchyma in each wing; roots arise from lateral edge of segments of traces in inner cortex.

REPOSITORY.—Brigham Young University 5041 (HOLOTYPE).

LOCALITY.—Uncertain, possibly the eastern slope of Angel Peak, northwestern New Mexico.

HORIZON.—Uncertain, possibly the San Jose Formation.

AGE.—Uncertain, possibly Early Eocene.

ETYMOLOGY.—The specific epithet is for Mr. Doug Moore of Glendora, California, for donating the specimens for this study.

DESCRIPTION.—The specimen (90 mm across  $\times$  85 mm tall) of *A. moorei* consists of a stem surrounded by petiole bases and adventitious roots (Figs. 1A, 2A, 3A). The base of the specimen is composed of roots and distorted leaf bases. A column of parenchyma cells 78–97  $\mu$ m in diameter in the center and a zone of thick-walled sclerotic tissue 6–10 cells wide around its periphery form the heterogeneous pith (Fig. 2F). The diameters of the sclerenchyma cells vary between 85 and 120  $\mu$ m with walls 10  $\mu$ m thick. The sclerenchyma typically projects into the leaf gaps for a short distance. Most of the parenchyma cells in the center of the pith have been destroyed and replaced with mineral matter.

The xylem cylinder is 2–3 mm across and contains 32–36 strands of xylem separated by

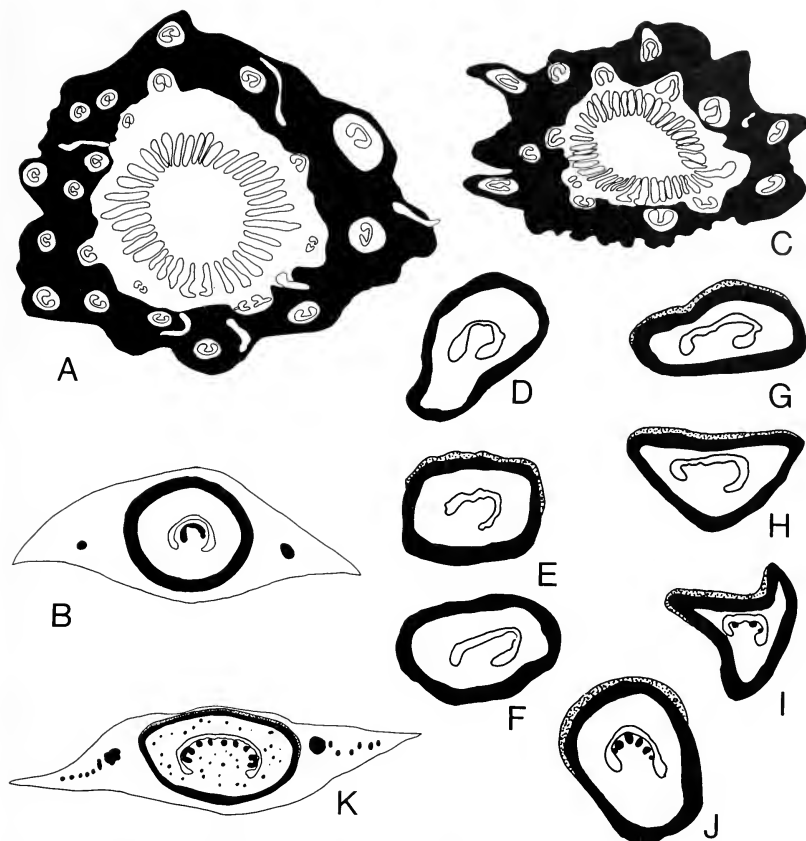
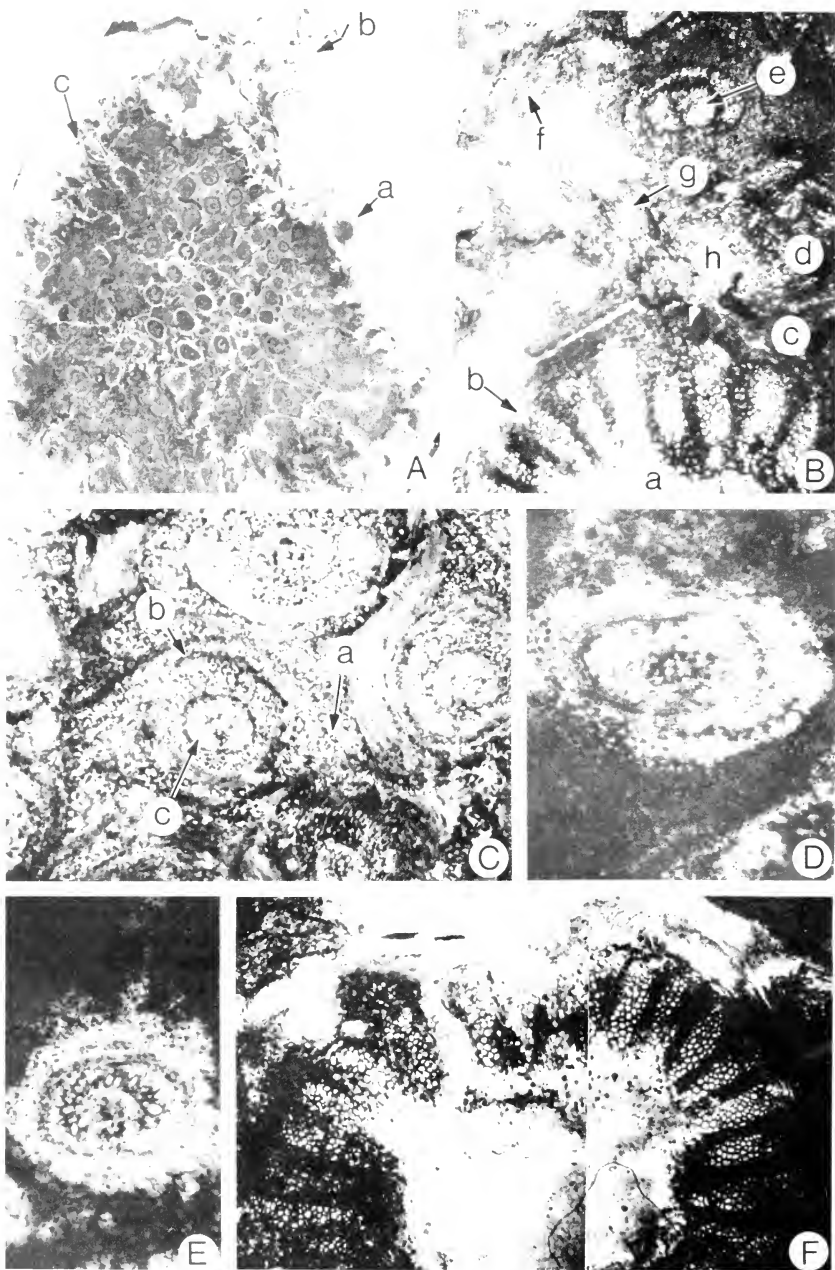


Fig. 1. A–B. *Aurealcaulis moorei* sp. nov. (5041, 1): A, stem, X4; B, petiole with attached stipular wings; note masses of sclerenchyma in each wing, X5; C–K, *Aurealcaulis bransonii* sp. nov. (5042, 1): C, stem X4; D–J, sequence of petioles from stem outward; note heterogeneous sclerotic rings in E, G–J, X5; K, petiole with attached stipular wings illustrating the abundance of sclerenchyma in the petioles and wings, X5. Black = sclerenchyma and sclerotic outer cortex of the stems (all transverse sections).

complete leaf gaps that do not show closure (Figs. 2B, 2F). Thus, the strands are distinct and do not connect with one another at any point. They have a radial thickness of 15–18 tracheids and are 3–6 metaxylem tracheids wide. The latter are 40–120  $\mu\text{m}$  wide by 400–650  $\mu\text{m}$  long and have scalariform pitting in their walls. Protoxylem groups are exarch on the external part of each xylem strand with individual elements that are 19–40  $\mu\text{m}$  in diameter.

A poorly preserved, discontinuous zone of thin-walled cells (1–2 cells wide) between the xylem and phloem represents the xylem sheath. It connects with the parenchyma in the leaf gaps. Cells of the gaps are radially elongated, paralleling the margins of the gap, and are 50–60  $\mu\text{m}$  long and 19–38  $\mu\text{m}$  wide. Sclerotic cells similar to those of the outer pith occur about one-third the length of the gap near the pith, and the radially elongated parenchyma cells occupy the remainder.



Leaf trace development begins when the exarch protoxylem groups on separate, but adjacent, strands face one another and then split off with connecting metaxylem elements, forming two distinct segments (Fig. 2D). These segments fuse and form a single C-shaped trace in the inner cortex (Fig. 2E). The protoxylem groups, one from each segment, become endarch in the trace, eventually dividing into as many as seven protoxylem points in the petiolar vascular strands (Fig. 1B).

Generally, poorly preserved phloem is crushed. The metaphloem appears to be 2–3 cells wide, the cells varying from 19 to 38  $\mu\text{m}$  in diameter. Protophloem is indiscernible.

The endodermis is represented by a line of crushed cells 20  $\mu\text{m}$  wide, filled with dark contents. It is continuous and separates the cortex from the stele.

Parenchymatous tissue of the inner cortex is composed of isodiametric (5–7  $\mu\text{m}$ ) cells near the endodermis and appears as a zone of tangentially elongated cells (30–50  $\mu\text{m}$   $\times$  100–150  $\mu\text{m}$ ) perpendicular to the xylem strands and surrounding the stele. Leaf traces in the inner cortex are surrounded by parenchymatous cortical cells and a thin endodermis as they leave this tissue. Also, prior to the segments fusing and then leaving this tissue, adventitious roots depart from their outer margins, usually from one segment first and then from the opposite one.

Homogeneous, sclerenchymatous tissue (cells 30–60  $\mu\text{m}$   $\times$  180–400  $\mu\text{m}$ ) composing the outer cortex encloses the departing C-shaped leaf traces after the segments have fused. This tissue forms the sclerotic ring around the traces.

At the point of departure, the leaf traces are 1–2 tracheids thick at their centers and 3–4 thick on their flanks (Fig. 2E). Continuous sclerenchyma is present in the adaxial concavities of the traces.

A crushed xylem sheath and phloem, 1–2 cells wide, are abaxial on the xylem of the petiolar vascular strands. A 3-cell-layered

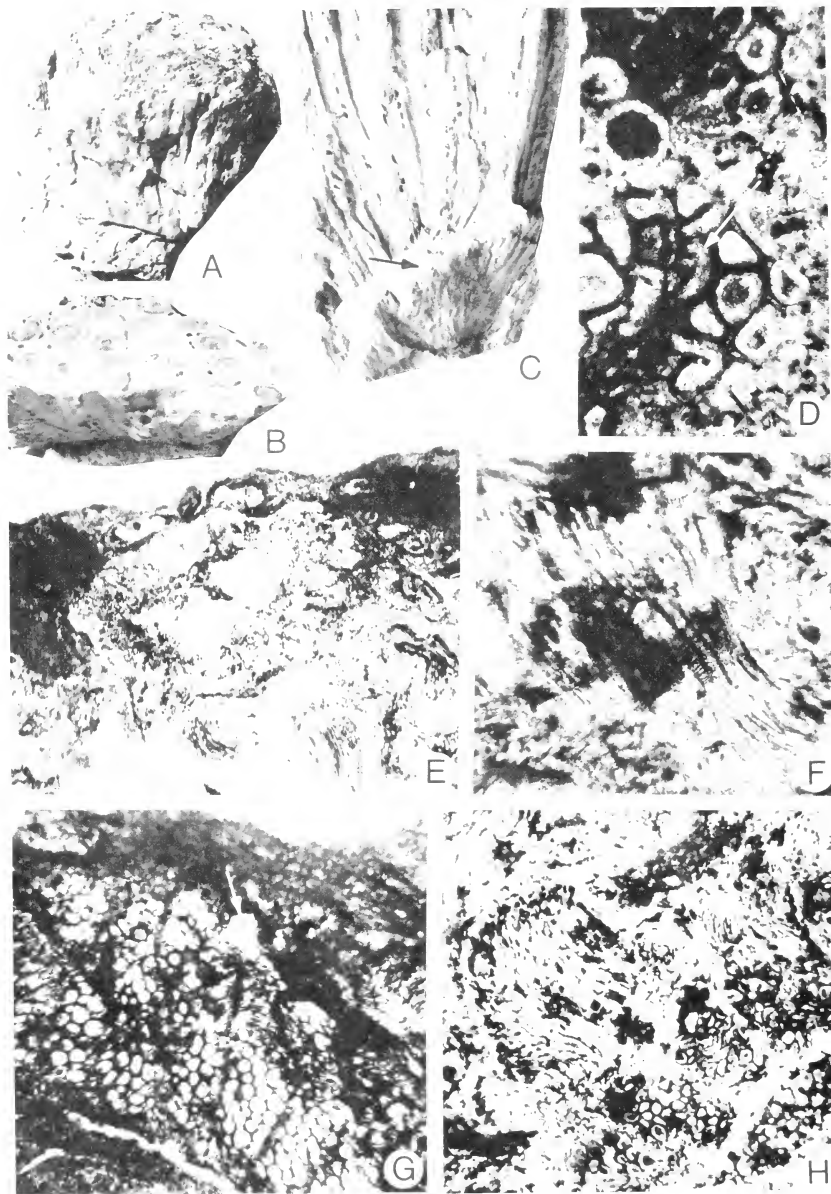
endodermis surrounds them, and crenate sclerenchyma is present in the adaxial concavity of these strands. The inner cortex of the petiole is composed of parenchyma cells 30–60  $\mu\text{m}$  in diameter. The fibers of the sclerotic ring are uniform in size, 30–60  $\mu\text{m}$  across, and continuous with those of the outer cortex.

Stipular wings of the leaf bases are shorter at lower levels, becoming longer at higher levels, and are often distorted by penetrating roots. Wing expansions are from 4 to 17 mm from tip to tip, with the parenchyma cells of the wings being 40–80  $\mu\text{m}$  in width and generally filled with dark contents (Fig. 2C). Epidermal cells are 10  $\mu\text{m}$  wide  $\times$  30–40  $\mu\text{m}$  in tangential length, and cuticle is not preserved. A 3-cell-wide palisade layer having cells 50–100  $\mu\text{m}$  long  $\times$  40  $\mu\text{m}$  wide is present immediately below the abaxial epidermis. One, occasionally two, strands of fibers 40  $\mu\text{m}$  or more across, composed of upwards of 80 cells with each cell being about 10  $\mu\text{m}$  wide, occur approximately one-half the distance between the sclerotic ring and the wing tip (Fig. 1B). Some stipular wings lack these groups of sclerenchyma.

Numerous adventitious roots occur throughout the specimen. They are diarch with the phloem, pericycle and endodermis being crushed. The metaxylem tracheids are 50  $\mu\text{m}$  and the exarch protoxylem tracheal elements 15  $\mu\text{m}$  in diameter. Cells of the parenchymatous inner cortex are 20  $\mu\text{m}$  wide and surrounded by a homogeneous, sclerenchymatous outer cortex. Most of the roots are cut transversely, which suggests an arborescent growth habit (Miller 1971).

**COMPARISON.**—*Aurealcaulis moorei* is proposed as a new species with the following characteristics: an erect to arborescent habit, a heterogeneous pith, nonclosure of its leaf gaps, formation of its C-shaped trace by fusion in its inner cortex of two segments from adjacent xylem strands, 16–22 traces in its cortices, sclerenchymatous outer cortex that connects with the sclerotic ring of the petiolar

Fig. 2 (see facing page). *Aurealcaulis moorei* sp. nov. (all transverse views): A, actual specimen (5041); stem (a) near edge of specimen with petiole bases (b) and roots (c) making up remainder of specimen, X1; B, close-up of a portion of the stem; pith (a), xylem strands (b), inner cortex (c), outer cortex (d), leaf trace (e), oblique section of two segments of a leaf trace, (f) is left side and (g) is right side, which is still attached to xylem strand (h) (5041, 1), X5; C, petiole vascular strands with stipular wings (a) attached; note sclerotic ring (b) surrounding the C-shaped strand (c) (5041, 1), X5; D, two segments of a leaf trace that have not completely fused (5041, 1), X15; E, leaf trace after segments have fused (5041, 1), X10; F, close-up of the xylem strands and the pith (5041, 1), X5.



vascular strand, leaf bases with crenate-shaped sclerenchyma lining the concavity of their vascular strands, and may or may not contain one, occasionally two, cellular masses of sclerenchyma in their stipular wings.

*Aurealcaulis moorei* differs from the other species of *Millerocaulis* and *Osmundacaulis* and from living members of the Osmundaceae (Hewitson 1962) in its manner of trace and root origination, its lack of gap closure, and the exarch protoxylem clusters in its xylem strands.

*Aurealcaulis moorei* can be distinguished from the generitype *A. crossii*, which was reported from the Paleocene Fort Union Formation near Rock Springs, Wyoming (Tidwell and Parker 1987), by its having a heterogeneous pith, fibrous outer cortex, and sclerenchyma in its petiolar strands and stipular wings, all of which are not present in *A. crossii*.

*Aurealcaulis bransonii*, sp. nov.

Figs. 1C-K, 3B-H, 4

**DIAGNOSIS.**—Erect, stem 15–20 mm across, surrounded by leaf bases and roots; stele 7 mm  $\times$  10 mm in diameter, dissected ectophloic siphonostele; pith 3 mm  $\times$  6 mm across, homogeneous, parenchymatous; xylem cylinder dissected, 35–40 xylem strands separated by narrow leaf gaps, strands 17–20 tracheids thick radially and 3–6 metaxylem tracheids wide, gaps generally lack closure, protoxylem exarch; phloem external; inner cortex parenchymatous, narrow, .05 mm wide; outer cortex 10 mm thick, homogeneous, sclerenchymatous; 15–19 leaf traces per cross section of cortices; two segments originating from adjacent xylem strands depart and fuse into C-shaped leaf trace in inner cortex; protoxylem becoming endarch; petiolar vascular strand curved; interrupted sclerenchyma adaxial to strand; sclerotic ring heterogeneous; stipular wings contain 6–8 masses of sclerenchyma aligned from near sclerotic ring to near tip; roots arise from lateral edges of segments of traces before they fuse.

**REPOSITORY.**—Brigham Young University 5042 (HOLOTYPE); 5043, 5044 (PARATYPES).

**LOCALITY.**—Uncertain, possibly the eastern slope of Angel Peak, northwestern New Mexico.

**HORIZON.**—Uncertain, possibly the San Jose Formation.

**AGE.**—Uncertain, possibly Early Eocene.

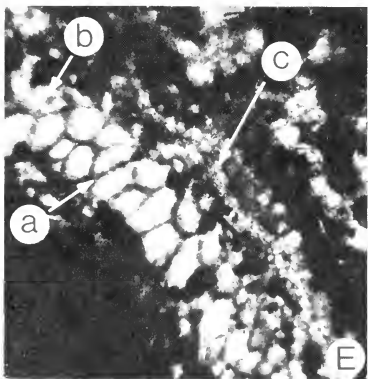
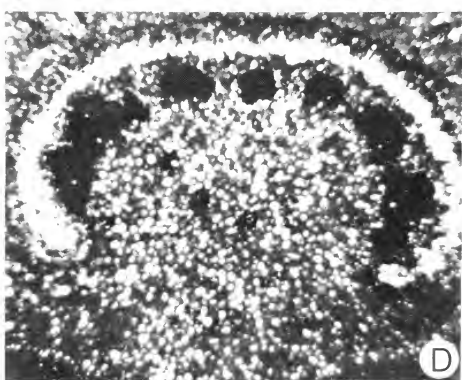
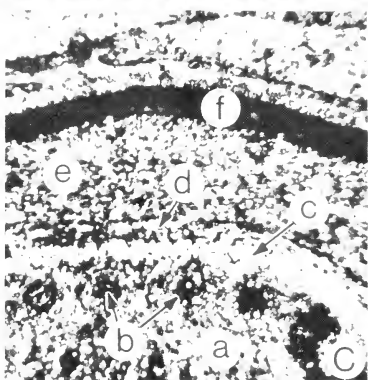
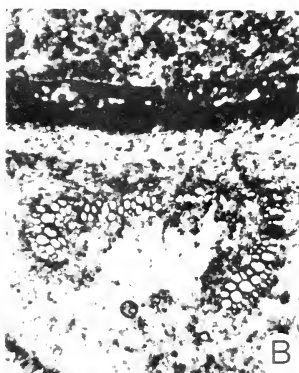
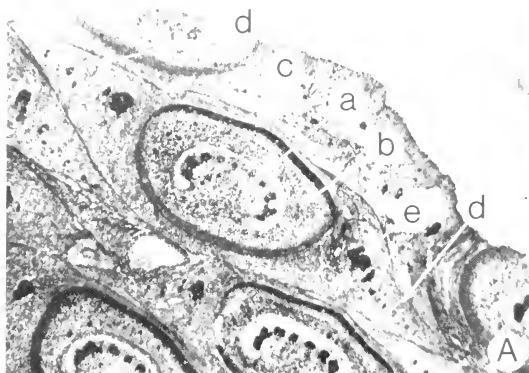
**ETYMOLOGY.**—The specific epithet is for Mr. William Branson of Helper, Utah, for his assistance with this study.

**DESCRIPTION.**—The holotype is 100 mm tall  $\times$  60 mm across, tapered, flattened, and split in half due to weathering (Fig. 3B). Its stem is present for about one-third the vertical distance of the specimen before it disappears because of erosion, and the leaf traces and petiole bases can be observed at various levels of the petioles (Fig. 3C). Roots appear between the petioles in longitudinal sections; whether they continued outwardly into or bent downwardly into the soil cannot be determined. Paratype (BYU 5043) is fairly large, 150 mm  $\times$  250 mm, and without a stem. The specimen is composed primarily of petiole bases, as is the other paratype (BYU 5044). The latter specimen is smaller (25 mm  $\times$  75 mm), but its curvature suggests the original was at least 600 mm in diameter.

The isodiametric parenchyma cells of the pith are 70–150  $\mu$ m in diameter and thin walled. They are filled with dark contents and in some areas are crushed.

The xylem cylinder is 1.5–1.75 mm wide and consists of strands generally separated from one another by the leaf gaps (Figs. 3E, 3G). These strands are only occasionally connected and then by 2–3 tracheids at most. Metaxylem elements in the strands are 70–150  $\mu$ m wide by 270–900  $\mu$ m long with scalariform pitting in their multifaceted walls (Fig. 3F). Many of these tracheids are filled with crystals. Their walls vary in thickness from relatively thin (10  $\mu$ m) to thick (25  $\mu$ m) with wide (50–120  $\mu$ m) to narrow (30–70  $\mu$ m) lumens. Protoxylem elements are also thick walled (Fig. 3D).

Fig. 3 (see facing page). A, Side view of holotype of *Aurealcaulis moorei* sp. nov. (5041), X4; B–H, *Aurealcaulis bransonii* sp. nov. (5042): B, side view of holotype; remains of stem near base (arrow) and roots projecting between petioles, X.75; C, top view of holotype showing transverse sections of petioles; note the stipular wings, X.75; D, close-up of tip of xylem strand illustrating protoxylem cluster (arrow) (5042, 1), X200; E, transverse section of the stem (5042, 1), X7; F, close-up of a longitudinal view of one-half of trace departing xylem strand; note the scalariform thickenings on the tracheid walls (5042, 1), X40; G, close-up of xylem strands; arrow indicates protoxylem cluster (5042, 1), X40; H, close-up of departing trace in longitudinal view (5042, 1), X25.





The phloem is 2–3 cells across and, along with the xylem sheath, pericycle, endodermis, and inner cortex, is poorly preserved. The space originally occupied by the xylem sheath is 20–40  $\mu\text{m}$  wide. It appears to have enclosed the xylem strands and formed the cellular tissue of the gaps.

Formation of the leaf traces and petiole bases is essentially the same as for *A. moorei* (Figs. 3H). The small number of leaf traces (15–19) in transverse section of the cortices and the general nonclosure of the leaf gaps suggest long internodes in this species.

The sclerenchyma in the concavity of the petiolar vascular strand appears at a higher level of the petiole. Initially, it is continuous but eventually becomes interrupted (Figs. 4C, 4D). Two clusters of sclerenchyma fuse together near the tips of the strand, but the remainder remain separate. The fibers of this tissue are angular, thick walled, and 5–12  $\mu\text{m}$  in diameter.

Metaxylem tracheids of the petiolar vascular strands are 30–70  $\mu\text{m}$  across and surrounded by a xylem sheath 1–2 cells wide (Fig. 4E). The phloem is 2–3 cells wide and enclosed by a single-layered pericycle with cells 7–15  $\mu\text{m}$  in diameter and a discontinuous, uniseriate endodermis having cells filled with dark contents. Cells of the inner cortex of the petiole are 20  $\mu\text{m}$  wide and thin walled, with clusters of sclerenchyma occurring irregularly in this tissue (Fig. 4C). Sclerotic rings of the petioles are heterogeneous, with the majority of the cells being thick walled and 30  $\mu\text{m}$  across, whereas the outer, abaxial 12 layers of cells are thinner walled and weather differently from the other cells of the ring. These rows of cells taper to one row on each side of the ring.

The thin-walled parenchyma cells of the stipular wings are 25–30  $\mu\text{m}$  across, and most are filled with contents (Fig. 4F). Cuticle and epidermis of the wings are poorly preserved, with the epidermal cells being 2.5  $\mu\text{m}$  wide. Six to eight masses of sclerenchyma occur in each wing. These masses are aligned from

near the sclerotic wing to the tip. The largest near the ring is 300  $\mu\text{m}$  in diameter, whereas the smallest is 150  $\mu\text{m}$  and near the tip. These masses comprise thick-walled fibrous cells 12–15  $\mu\text{m}$  wide.

The roots of *A. bransonii* are like *A. moorei* and weave their courses between the stipular wings of the petioles. Roots invading the wings are relatively rare.

COMPARISON.—*Aurealcaulis bransonii* has a homogeneous pith and partial closure of its leaf gaps similar to *A. crossii*, but unlike *A. moorei*. *Aurealcaulis bransonii* has a lower trace number in its cortices than the other two, interrupted sclerenchyma in the concavity of its petiolar strand, a heterogeneous sclerotic ring, and 6–8 masses of sclerenchyma in its stipular wings, none of which are present in either *A. crossii* or *A. moorei*.

## DISCUSSION

Because *A. moorei* and *A. bransonii* vary from the genus *Aurealcaulis* as previously defined (Tidwell and Parker 1987), the genus is emended slightly in this report to contain species assignable to this genus, but having such variations as heterogeneous or homogeneous piths, protoxylem becoming endarch in the leaf traces, petiolar vascular strands formed by fusion of segments from the xylem strands in the inner cortex, outer cortex, or outside of the stem, and occurrence or non-occurrence of sclerenchyma in the adaxial concavity of their petiolar vascular strands and in their stipular wings.

The occurrence in *Aurealcaulis* of thin-walled cells in its inner cortex, closely adhering petiole bases, and external phloem and endodermis represents a primitive condition for this genus in the Osmundaceae (Miller 1971). The fact that species of *Aurealcaulis* are exarch and arborescent places them among the more primitive members of the family. Based upon seven primitive to advanced characters proposed by Miller (1971) for this family with an additional one specific to

Fig. 4 (see facing page). *Aurealcaulis bransonii* sp. nov. (all transverse sections): A, leaf base illustrating petiolar vascular strand (a), outer cortex (b), sclerotic ring (c), and stipular wings (d) containing masses of sclerenchyma (e) (5042, 1), X7; B, close-up of petiolar vascular strand after departing from stem (5042, 1), X25; C, close-up of vascularization of a petiole showing inner cortex (a), sclerenchyma in adaxial configuration of strand (b), xylem (c), phloem (d), outer cortex (e), and sclerotic ring (f) (5042, 1), X25; D, same as Fig. 4C showing more inner cortex of petiole, X25; E, enlargement of a portion of Fig. 4C xylem (a), xylem sheath (b), and phloem (c); endodermis and pericycle are poorly preserved, X75; F, stipular wing containing masses of sclerenchyma: note the epidermis (arrow) (5042, 1), X25.

TABLE 1. Comparison of *Aurealcaulis* species.

	<i>A. crossii</i> Tidwell & Parker	<i>A. moorei</i> sp. nov.	<i>A. bransonii</i> sp. nov.
Pith	homogeneous	heterogeneous	homogeneous
Xylem strands	55	32–36	35–40
Number of traces in cortex	28–30	16–22	15–19
Outer cortex	not fibrous	fibrous	fibrous
Sclerenchyma in stipular wings	none	may or may not be present	6–8 aligned masses
Age	Paleocene	Lower Eocene(?)	Lower Eocene(?)

*Aurealcaulis*, *A. bransonii* seems to be the more advanced of these species of *Aurealcaulis* and *A. crossii* the most primitive (Table 1). The general trend of less sclerenchyma in less specialized ferns (Wagner 1964) appears to apply to *Aurealcaulis*. *Aurealcaulis moorei* would be more advanced with its heterogeneous pith, but this is offset by having only an occasional mass of sclerenchyma in its stipular wings and, like *A. crossii*, a homogeneous sclerotic ring. *Aurealcaulis crossii* lacks any sclerenchyma in its wings, a primitive character, whereas *A. bransonii* has 6–8 masses in each wing and is thus more advanced. The inner cortex of the petiole of *A. bransonii* has irregularly shaped clusters of sclerenchyma and a heterogeneous sclerotic ring, both of which are considered advanced characters. These features are lacking in the other two species. Supported by their possible geologic ages, the fusion of the segments in the outer cortex of the older *A. crossii* (Paleocene) may be more primitive than fusion of these segments in the inner cortex of the younger *A. moorei* and *A. bransonii* (possible Eocene). Another probable character is the reduction in the number of strands in the xylem cylinder from 50–60 for *A. crossii* to 32–36 for *A. moorei* and 35–40 for *A. bransonii*.

Among living members of the Osmundaceae, the petioles of *A. bransonii* most closely resemble species of the subgenus *Plenasium*, particularly *Osmunda banksiaefolia* (Hewitson 1962). Distribution of the sclerotic masses in the inner cortices of their petioles and stipular wings is quite similar. The crenate-shaped sclerenchyma lining the adaxial concavity of the strand in *O. banksiaefolia* is like that of *A. moorei* and unlike that of *A. bransonii*, which is interrupted. The xylem cylinders of taxa of the *Plenasium*-type are distinctively different from those of the *Aurealcaulis* species.

The phylogenetic sequence in *Aurealcaulis* is unclear and appears to represent a unique osmundaceous line that became extinct. The ancestor of this genus is unknown. With some modifications, however, earlier members of the *Aurealcaulis* evolutionary line may have arisen from an ancestor common to both them and the subgenus *Plenasium*. It is interesting that a large number of the species of *Millerocaulis* (Tidwell 1986) and most members of *Osmundacaulis* (*sensu stricto*) appear to be related in some way to the subgenus *Plenasium*. Certainly not all members of *Millerocaulis* and *Osmundacaulis* similar to the *Plenasium* subgenus can be its ancestor (Tidwell 1987). However, if the hypothesis of *Aurealcaulis* and *Plenasium* having a common ancestor is correct, then older forms of *Aurealcaulis* should be encountered eventually.

If these species come from the San Jose Formation, then the environment of the Angel Peak area where *A. moorei* and *A. bransonii* may have occurred can be determined by the associated impression-compression flora (Tidwell et al. 1981), as well as these osmundaceous species. Modern relatives of the flora from Santos Peak occur in moist environments, and living members of the Osmundaceae grow in tropical to cool temperate climates and can be found in bogs, swamps, rain forests, and damp woodlands (Gould 1981). An axis of *A. crossii* was collected in growth position in a lignitic bed of the Fort Union Formation, indicating that this species had grown in swamps. Furthermore, the area in which *A. crossii* occurred seems to have been a forest that grew under swampy conditions on a flat flood plain in a subtropical to warm temperate climate (Brown 1962, Roehler 1979). *Aurealcaulis moorei* and *A. bransonii* very likely grew under similar conditions. It can be concluded, therefore, that the San Juan Basin was, in general, a humid, forested region during the time these plants grew.

## ACKNOWLEDGMENTS

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## HOLOCENE BISON FROM ARCHES NATIONAL PARK, SOUTHEASTERN UTAH

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**ABSTRACT.**—An artifact constructed from a bison (*Bison bison*) hornsheath was recovered from the surface of a sandstone shelter also containing skeletal remains of bison and bighorn (*Ovis canadensis*). Radiocarbon dating of bison, bighorn, and the artifact indicate that all co-occurred on the central Colorado Plateau, southeastern Utah, either between A.D. 1405 and A.D. 1420, or between A.D. 1535 and A.D. 1605. Skeletal remains of the bison imply that the animal was of the local faunal community during the transition between Protohistoric and Historic time.

**Key words:** bison, Bison, Holocene, bighorn, *Ovis canadensis*, Colorado Plateau.

### BISON ALCOVE

Bison Alcove (our informal designation for locality 42GR538) is a large shelter located in the Entrada Sandstone in Arches National Park, Grand County, southeastern Utah (1317 m elevation). A sparse pinyon-juniper community occurs on the predominantly eolian sandy alluvium outside the south-facing entrance. The entrance to the dry rock shelter is approximately 10 m high and 22 m wide (Fig. 1). Much of the interior is choked with large roof spall boulders; however, one can easily proceed horizontally about 13 m into the shelter. Packrat (*Neotoma*) middens are common throughout the site. Initial analyses of seven of the indurated (cemented) middens, radiocarbon dating 12,400 to 20,000 years before present (yr B.P.) (S. Sharpe, in progress), indicate that Pleistocene-age materials (limber pine [*Pinus flexilis*], Douglas fir [*Pseudotsuga menziesii*], and numerous microfauna) occur at the site.

The entrance to the alcove is somewhat flattened and cleared of rubble in spots; higher up into the shelter many of the small boulders and larger packrat middens have been assembled to form one- or two-tier, dry-laid walls. Sand is deflating outside the alcove and uncovering lithic debitage. Pottery is rare. Two unindurated packrat stick middens occur in the shelter: one small nest at the east side of the entrance, and one large midden occupying the back of the shelter. In both

cases these middens contain numerous skeletal elements of large and small mammals. The dry environment outside the alcove and the protective nature of the shelter have permitted the preservation of various specimens of keratin tissue (horn and hoof) from herbivores. A vandal's pothole occurs near the midden at the entrance area. Just upslope from this hole, and under a boulder where packrat activity occurs, we recovered an artifact made from hornsheath.

We felt that the alcove and its deposit required additional analyses due to the remains of bighorn (*Ovis canadensis*) and bison (*Bison bison*), the excellent preservation of keratin, and the recovery of the horn artifact. Although bighorn lived in the region throughout the Holocene, they were reintroduced to the park in 1985. The chronological range of the bison is inadequately understood for the Colorado Plateau. Given the known occurrence of Pleistocene packrat middens, it was conceivable that the artifact was also of late glacial age. This is a report of the bighorn and bison remains and bison artifact recovered from Bison Alcove, Arches National Park.

### PACKRAT MIDDEN

Packrats typically collect plant, rock, animal (dung, hair, keratin, and skeletal), and artifactual material from within a range of 30–100 m of their den. These materials are placed over the nest mainly for protective

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## 42 GR 538, BISON ALCOVE Arches National Park, Utah (Schematic Plan Map)

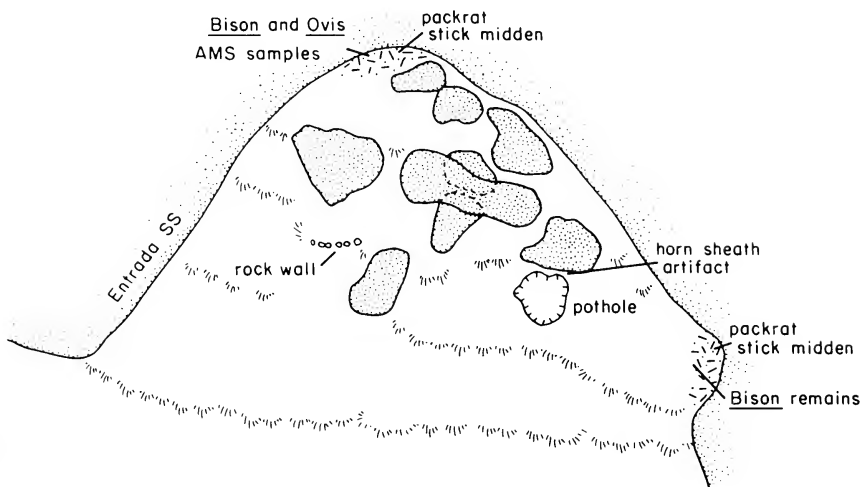


Fig. 1. Schematic plan map of Bison Alcove, Arches National Park.

construction. Often the packrat collects recently "living" materials, such as fresh plants, dung, and animal carcass remains. If the den construction is in a dry alcove in the hyperarid Southwest, the resulting midden will last as long as the shelter persists and represents the local biotic community at the time of collection (Betancourt et al. 1990). This same dry shelter may also preserve much older Pleistocene material, which the packrat may incorporate into a "recent" midden. Any item found loose in the dry alcove is "fair game" for a rummaging packrat.

The undurated middens described above contained numerous bones of bighorn and bison. These materials could conceivably have been of late Pleistocene age, or they could be Holocene remains procured by local humans or packrats. The sample of large mammal bones was collected from the undurated packrat midden in the back of the shelter; the artifact was collected from the surface near the front of the alcove. Due to the dry environment and continued preserva-

tion in the alcove spanning at least the past 20,000 years, precise age determination of the remains can occur only through direct radiocarbon dating.

### FAUNAL REMAINS

#### *Ovis canadensis*

Bighorn remains were the most numerous large mammal remains in Bison Alcove. The following skeletal elements were recovered: horncore with sheath ( $n = 1$ ) (Fig. 2A), axis (2; one burnt), thoracic vertebra (2), sacrum (2), scapula (1), tibia (1; distal fragment), metatarsal (1; distal fragment), and 2nd phalanx (1). Some of these remains exhibit tissue still adhering to the bone. Although no butchering marks are evident, the burning and the location of fragmentation could imply human usage. A minimum number of individuals (MNI) of two bighorn was represented, based on the sacrum.

The horncore remain, although fragmented and removed from the skull, was from a young

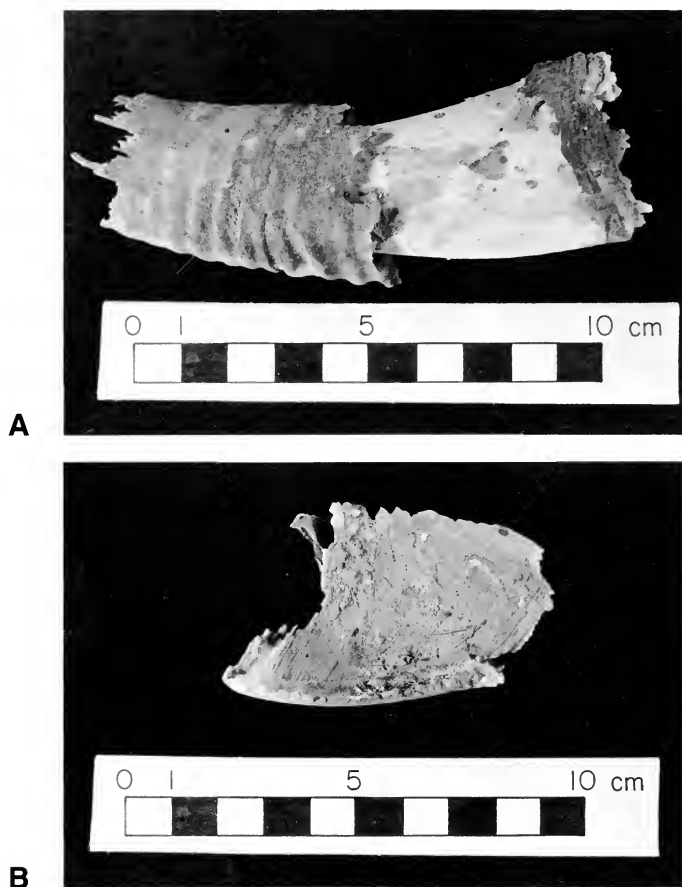


Fig. 2. Skeletal remains from the packrat midden: A, horncore and attached sheath of a young adult bighorn, *Oris canadensis*; B, hoof remain of a young bison, *Bison bison*. Samples of keratinous tissue were removed from each specimen for AMS radiocarbon dating.

adult, possibly a female, based on the amount of internal core ossification and the length cross-section shape of the core and sheath. The unburned axis shows extreme degradation due to prolonged exposure to sun and possibly moisture. This bone was probably collected by the packrat from either outside the shelter or from the dripline area.

#### *Bison bison*

Bison remains were found throughout the shelter, but never in great quantity. The following skeletal elements were recovered

(Fig. 2B): hornsheath (1; fragment constructed into artifact), centrum plate (2), ulna (1; proximal fragment), 1st phalanx (1), 2nd phalanx (3), 3rd hoof phalanx (3), and keratin hoof (1). No butchering marks were observed on any of these bones, although evidence of rodent gnawing was common. There appears to be an MNI of one bison. The size of the terminal phalanx, the unfused centrum vertebral plates, and the hollow length versus the diameter of the hornsheath suggest that the bison was a young adult.



Fig. 3. Artifact made of bison horns sheath and pine pitch. Dermestid beetle chewing can be seen at the left end and top of the horns sheath. A knife cut mark is seen near the basal edge of the sheath adjacent to a circular groove used to cut the sheath from the horncore.

#### ARTIFACT DESCRIPTION

The artifact contains three parts: horn-sheath, twig, and resin (Fig. 3). The total length is 163 mm, the horns sheath 50 mm, resin 16 mm, and protruding twig 97 mm. The horns sheath base is straight and contains a hollow center, indicating that it was cut from the burr and horncore of the bison skull. An isolated cut mark is seen above the base of the horns sheath (Fig. 3). The horns sheath now shows the burrowing damage of dermestid beetles; furrowing can be seen on the top edge of the sheath in Figure 3 and along the tip. It cannot be stated whether the tip of the horn was present when the artifact was constructed because it has since been consumed by beetles. Although it is possible that a human used an older, beetle-eaten horns sheath, the radiocarbon dates (see below) do not confirm this idea.

The resin is pine (*Pinus*) pitch; juniper (*Juniperus*) does not produce pitch in quantity. Most pitch exudes predominantly from a wound to the tree and stays malleable for approximately one to two years, after which it crystalizes (M. Wagner, Northern Arizona University). Pitch balls are preserved under trees in arid climate, such as in Arches National Park, and potentially can last for hundreds of years in the right environment.

A scenario of construction of the artifact follows: (1) The human procures a bison horn-sheath. (2) Pine resin is pushed and molded into the base of the hollow (natural) horn-sheath. (3) A twig of unknown identification is pushed into the soft resin before it hardens.

The function of this artifact is not understood; it would be pure speculation to identify this object as a "religious device," a tool, or a child's toy. A search through the Southwestern archaeological literature has failed to locate any examples of objects similar to this bison artifact. Morris (1980) illustrates a corn (maize) cob that contains a stick in one end and a feather inserted into the other end. The appearance is vaguely similar to our bison artifact. Morris (1980:139) states that these corn artifacts "may have been game darts, prayer sticks, or other ceremonial material" belonging to the Basketmaker people in the Prayer Rock district (tree-ring dating between A.D. 446 and A.D. 676), at the north end of the Lukachukai Mountains, Arizona.

#### RADIOCARBON DATING

Four samples were submitted for radiocarbon dating using the accelerator mass spectrometer (AMS) technique. All radiocarbon analyses were conducted by Beta Analytic Laboratories (Gainesville, Florida). A keratin

hornsheath of *Ovis canadensis* and the isolated keratin hoof of *Bison bison* were selected from the unindurated midden located in the back of the alcove to provide direct dates on these species. Milligrams of keratin of each species were used in the analyses.

The bison artifact was dated twice using two different segments of the specimen (hornsheath and resin). Initially it was assumed that the hornsheath could be of late Pleistocene age, based on other Pleistocene plant and animal remains preserved within the packrat middens and the alcove; but the artifact could have been manufactured at a much later time. We assumed that dating the sheath would provide a time for the species presence at the alcove, and the analysis of the resin would determine the age for the manufacture of the artifact.

Figure 4 provides the radiocarbon age plus two standard deviations for each of the AMS dates. Uncorrected ages span a time, at two standard deviations of the mean, from A.D. 1180 to A.D. 1715 (720 to 235 yr B.P.). The radiocarbon ages illustrated in Figure 4 indicate that three of the dates are statistically the same age at one standard deviation of the mean (*Ovis* hornsheath, *Bison* hoof, and the *Bison* hornsheath). The resin in the artifact is older than the other three, but it is within a single grouping at two standard deviations. There are two scenarios for the use of the radiocarbon dates: (1) Group all four dates together at two standard deviations and determine the co-occurrence age. (2) The resin is actually an "old pitch ball" (see above) by a hundred years or so, and therefore the actual age of the remains is best determined by omitting the resin date and calculating the co-occurrence age at one standard deviation of the mean for the three youngest dates.

All dates can be considered a single event in time (at two sigmas), having occurred between A.D. 1425 and A.D. 1490 (stippled area in figure; scenario 1). Holocene radiocarbon dates should be calibrated because of temporal variations in the radiocarbon content of atmospheric carbon dioxide. Numerous calibration techniques occur (including Ralph and Michael 1970, Stuiver and Reimer 1986). At the 95% confidence level using the calibration technique of Klein et al. (1982), our four dates fall within a time span of A.D. 1280 to A.D. 1650. A grouped overlap area within

this calibration implies a possible single co-occurrence between A.D. 1405 and A.D. 1420 (Fig. 4). A high-precision calibration of the radiocarbon dates and a grouped overlap of corrected ages still implies a time of procurement and manufacture within the A.D. 1400s (Stuiver and Pearson 1986).

Scenario 2 is also depicted in Figure 4. By omitting the resin date, the co-occurrence age at one standard deviation is from A.D. 1535 to A.D. 1605, providing the implication that the bison, bighorn, and artifact were all utilized during the early historic period. Either scenario is reasonable to pursue.

#### DISCUSSION AND CONCLUSIONS

The question arises as to whether or not the bison remains were locally procured, either by humans or packrats, or brought to the alcove as a traded or long-distant-hunted carcass; i.e., were bison present in Arches National Park in A.D. 1400 to A.D. 1600? One way to attempt to answer the question is to examine the represented bison bones. Wheat (1972:101) states that

... virtually all sources, both historic and ethnographic, concur in listing the choicest parts of the bison as the tongue, hump ribs with meat, marrow bones, and ribs, in about that order.

It is implied that if only these bones are recovered from a site, it can be assumed that the bison was brought into the area by trade for "choicest" meat parts (Wheat 1972, Driver 1990). Had the carcasses been locally procured, more of the animal (e.g., phalanges, pelvic region, etc.) would be recovered.

The list of bison bones presented here is biased in two ways. First the sample of bones is a grab sample of the bones we saw in the unindurated packrat midden. We did not systematically sample all the bones from the midden. Second, the bones represented in the midden are of the size that can be carried by a packrat. A bighorn radius, metapodial, or single mandible is about the maximum size and weight of bones observed to be carried by the largest packrat species (bushy-tailed packrat, *Neotoma cinerea*); this packrat presently inhabits the alcove. Marrow-containing bones (humerus, tibia, femur), if present in Bison Alcove, most likely would not have been incorporated into the midden by the packrat due to their large size.



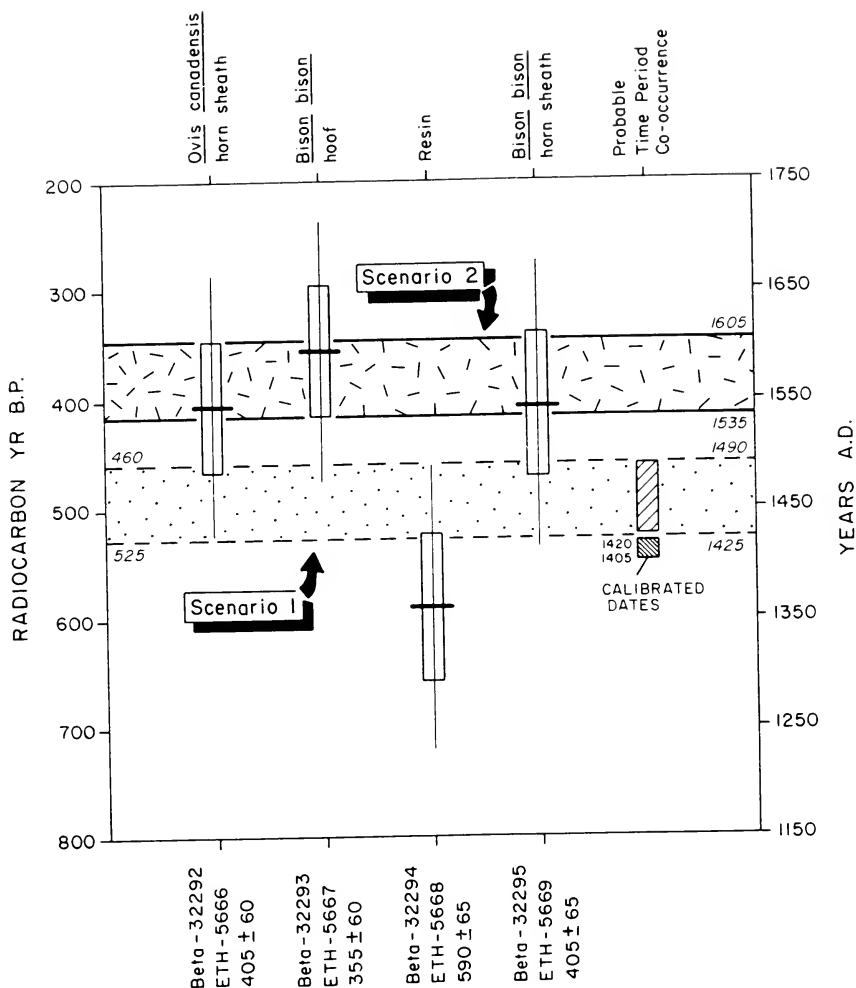


Fig. 4. Graph of the AMS radiocarbon dates from the bighorn and bison skeletal and artifact remains. Laboratory numbers and actual radiocarbon date are at the bottom. Material dated is at the top. One (box) and two (vertical line) standard deviations of the date (horizontal line) are shown for each date. See text for discussion.

These biases should not affect our determination of whether or not the bison was locally procured. We did recover some leg elements (phalange and ulna), some vertebral elements (unfused centrum plates), and a fragment representing the skull. Although the horns sheath could have been traded, the other elements

are not from the "choicest parts." We therefore feel that the young bison must have been a local community inhabitant.

It is possible that bison, albeit rarely to occasionally, roamed through Arches National Park during A.D. 1400s to A.D. 1600s. One could have died near Bison Alcove, and

only the packrat-size portions were collected by *Neotoma* and carried back to the shelter. What appears more likely, given the construction of the bison hornsheath artifact, is that a bison was procured (scavanged or hunted) near the alcove by humans. The bison carcass was rendered outside the alcove, and the "choicest parts" were either carried away from the site for later consumption or consumed at the site, with the larger bones later scattered by carnivores. The small-element bones were taken by the packrat and placed into its midden at the back of the alcove.

Bison are well documented as having lived in a wide variety of habitats on the Colorado Plateau during the late Pleistocene (Lindsay and Tessman 1974, McDonald 1981, Mead and Agenbroad 1989). The Holocene record of *Bison* on the Colorado Plateau is less well understood, but they were present at least rarely during protohistoric times.

#### ACKNOWLEDGMENTS

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## RADIO HARNESS SYSTEM FOR BOBCAT KITTENS

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**ABSTRACT.**—Eight bobcat kittens were fitted with a specially designed harness system supporting a radio transmitter. These kittens were the youngest known to be radio-instrumented. This system was used successfully through two seasons, from June 1989 to January 1991. Litters of kittens were located soon after birth for weighing, marking, and aging (by tooth eruption). During the first year when kittens were at least eight weeks old and six weeks old the second year, attempts were made to radio-instrument kittens in each litter. This harness system allowed litters to be located periodically until their death or dispersal. We were able to collect important data during the most crucial and least known weeks of the lives of bobcat kittens.

**Key words:** bobcat, *Felis rufus*, kitten, radio telemetry, behavior, mortality, break-away harness, Utah.

Little information has been generated concerning the first 48 weeks of life for bobcat kittens (*Felis rufus*). McCord and Cardoza (1982) and Jackson (1986) reported these first weeks of life were crucial to further development of hunting and predator-avoidance skills that enable the dispersal of experienced bobcat kittens. Our study of bobcats made it increasingly clear that habitat selection, location of prey, location of fresh water, and successful predator avoidance are all important factors directly related to survival of bobcat kittens.

Radio-instrumented collars have been used successfully to collect data on bobcats in many areas (Bailey 1974, Karpowitz 1981, Lawhead 1984, Jackson 1986, Litvaitis et al. 1986). However, due to the rapid growth of bobcat kittens in their first year, the fixed collar used for adult bobcats was not considered an option. Intraperitoneal-implanted transmitters were also not considered a safe option for kittens for fear that in recovering from surgery they would not be able to keep up with the normal movements of the litter and might have difficulty competing for food. Jackson et al. (1988) developed an expandable, drop-off harness for bobcat kittens five months or older, which he used in Colorado.

After our first year of study concerning the reproductive habits of female bobcats and their young in Utah, we felt it necessary to develop a radio-instrumented harness that

would fit smaller and younger kittens yet expand to fit juveniles. By modifying Jackson et al.'s (1988) design, we were able to develop a harness successfully used on bobcat kittens as young as six weeks old.

This study tested the hypotheses (1) that an expandable, drop-off, radio-instrumented harness could be successfully used on bobcat kittens as young as six weeks old and (2) that the harness would neither alter normal behavior nor contribute significantly to mortality.

### STUDY AREA

The Sheeprock and Tintic mountains of the Wasatch National Forest and adjacent private property, as well as lands administered by the U.S. Bureau of Land Management, were established by the Utah Division of Wildlife Resources as a study area in 1987. Most of the area is closed to all harvest and pursuit of bobcats. Included are portions of Tooele and Juab counties in northwest central Utah. Sagebrush–desert shrub, pinion-juniper, mountain brush, and montane mixed forest are the common vegetative zones (Johnson 1989). Average annual precipitation ranges between 15.2 and 25.1 cm, with amounts increasing with elevation. Elevations range from about 1600 m to 2827 m. These mountains are typical of the cold-desert portion of the northern Great Basin.

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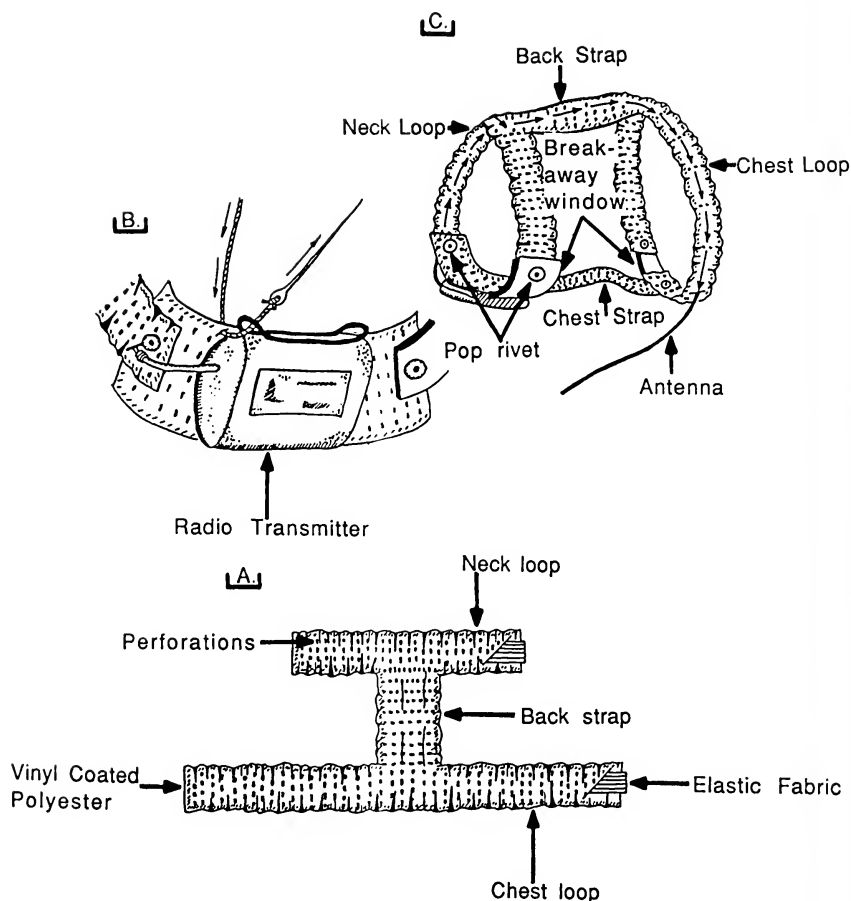


Fig. 1. An expandable, drop-off, radio-transmitter harness constructed for use on kittens at least six weeks old. (A) One-piece harness with elastic fabric before harness was assembled. (B) Attachment of radio transmitter to neck loop. (C) Completed harness; neck and chest loops are 1.5 cm wide and elastic fabric is encased in vinyl-coated polyester (VCP). Neck loop expands from 15.5 to 26 cm, chest loop from 24 to 54 cm. Back strap (3 cm long  $\times$  2 cm wide) and chest strap (6 cm long  $\times$  1.5 cm wide) are made of VCP. Antenna is encased by two sandwiched layers of VCP.

#### HARNESS CONSTRUCTION

Neck and chest loops, constructed of 1.3-cm-wide elastic fabric, were completely covered by a layer of brown vinyl-coated polyester (VCP) reinforced with imbedded woven nylon string (Fig. 1A). VCP is a perforated fabric and allows sunlight to penetrate to the rubber fabric, thus increasing potential for time-based disintegration. These perfora-

tions are approximately 2 mm  $\times$  1 mm (10 per 1 cm<sup>2</sup>). Neck and chest loops, as well as the back strap, were constructed in one piece in the shape of a capital H (Fig. 1A).

The VCP chest strap was pop-riveted to the chest loop and sewn to the neck loop with waxed upholstery cord. A small radio transmitter (Telonics Inc. Model 070, Mesa, Arizona) was stitched, with waxed upholstery

cord, to a wider piece of VCP fabric inserted at the bottom of the neck loop (Fig. 1B). The antenna for the transmitter, encased in the VCP harness, protruded slightly from the chest loop at the bottom (Fig. 1C). The edges of the VCP harness were double stitched with nylon thread. The completed width of the chest and neck loops was 1.5 cm, the back strap was 2 cm wide  $\times$  3 cm long, and the chest strap was 1.5 cm wide  $\times$  6 cm long.

The neck loop circumference was 15.5 cm and expanded to 26 cm, while the chest loop was 24 cm and expanded to 54 cm. The average weight of the completed harness system was 46.5 g, less than half the weight of the harness used by Jackson et al. (115 g; 1988).

### RESULTS

To place the harness on the bobcat kitten, we stretched and pulled the neck and chest loops over the bobcat's head. The neck loop rests in front of the shoulders on the neck, with the transmitter under the chin (Fig. 2A). The chest loop fits behind the front legs, with the legs straddling the chest strap (Fig. 2B).

We radio-instrumented eight bobcat kittens (four males, four females) (Table 1). One male kitten harnessed at nine weeks wore the harness system for 28 weeks, at which time the harness was replaced with a regular one-piece collar worn by other adult bobcats. We found the harness in very poor condition, as we had expected. We estimated that the harness would have fallen off in approximately three to four more weeks. There were no abrasions or sores caused from wearing it.

The harnesses were worn by the kittens for a varied number of days (Table 1), the least being two days, the most 32 weeks. One kitten was able to free itself from the harness because elastic inside the VCP was purposefully cut when the harness was first placed on the kitten. One kitten apparently hooked the back strap on a branch of a prostrate juniper tree and in its struggle to free itself twisted the harness tighter around the branch and its neck.

### DISCUSSION

Only one kitten, which wore the harness for 32 weeks, was found to have harness-related sores present on the neck and in the chest loop

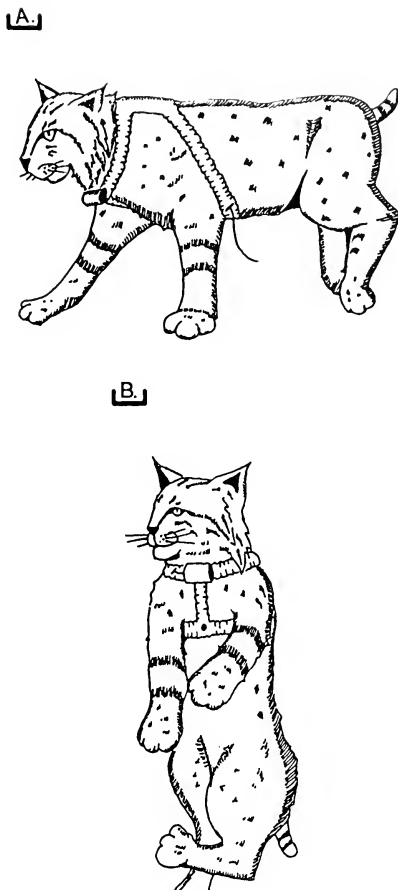


Fig. 2. (A) Side view of bobcat kitten wearing harness. (B) Bottom view of harness worn by bobcat kitten with front legs on either side of chest strap.

area. Because of this, we added two break-away windows (Fig. 1C) to the neck and chest loops, factors that will greatly increase the probability that the harness will break away before causing abrasive injury to the kitten.

Steigers and Flinders (1980) developed a break-away, expandable collar for mule deer fawns. We recommend this same type of break-away system for the bobcat kitten harness to ensure a complete and timely loss of the harness. Steigers and Flinders found

TABLE 1. Results of radio-instrumented harness system fitted to eight bobcat kittens, 1989–1990.

Bobcat kittens	Age (weeks)	Weight (g)	Harness use (weeks)	Results
17M male	9	1600	25/replaced	dispersed
22M male	18	3200	13	death/starvation
24F female	14	1900	16	death/predation
29F female	8	1480	4	radio stopped
30F female	8	1210	2 days	slipped harness
33M male	6	1100	7	death/natural
34F female	6	1050	3	death/harness
35M male	9	1610	32	collar broke away

that surgical tubing (0.318-cm wall thickness  $\times$  1.27-cm diameter) had an approximate life of 10–13 months and recommended thinner tubing for shorter life. We recommend 0.159-cm-thick tubing and are confident that this addition will meet our objectives for future use.

We have found that valuable data can be collected on mortality rates and behavior of young bobcats with this harness system. Not counting the harness-related death, there was a high natural mortality rate for the kittens. Two of the seven died of natural causes while wearing the harness. Two that grew large enough to wear adult radio collars were lost as juveniles: one died of starvation or disease, and the other disappeared during dispersal. Our data show there is a high mortality rate at all stages for young bobcats (Table 1).

By taking simultaneous readings of locations for collared dam bobcats and offspring with harnesses (and in one case between two siblings harnessed at the same time), we were able to study patterns of movement, home-range use, and family continuity. All kittens had a lower average daily minimum movement than their dams, confining their activities almost exclusively to the core area of the dams' home ranges (determined with Program Home Range, Ackerman et al. 1989). Kittens were found up to 1.5 km apart, but one would be with the mother and the other in a secure den. The mother was located with at least one of her kittens 50–80% of the time. When the mother was not with the kittens, she was found up to 2 km away. This suggests that estimates of kitten survival may not be very accurate if based on observations of kittens seen with their dams.

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## FLOWER MITES OF TRINIDAD II. THE GENUS *PROCTOLAEALAPS* (ACARI: ASCIDAE)

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**ABSTRACT.**—Nine species of mites of the genus *Proctolaelaps* were collected in flowers or phoretic in the nares of hummingbirds in Trinidad. Previously named species *P. kirmsei*, *P. glaucis*, and *P. belemensis* are redescribed, and six new species are described: *P. jurgatus*, *P. mermillion*, *P. rabulatus*, *P. contumex*, *P. certator*, and *P. contentiosus*. *Proctolaelaps belemensis cyanocompsae* is raised to specific status. Host plants are given for all species except *P. mermillion*, which was collected only from a hummingbird host. New World flower-inhabiting *Proctolaelaps* are grouped into two hypothetically monophyletic lineages, the *kirmsei*-group and the *belemensis*-group, on the basis of adult morphology. A key to the nine Trinidadian species is given.

**Key words:** *Trinidad*, *flower mite*, *Proctolaelaps*, *Ascidae*, *hummingbird*.

Mites of the family Ascidae are common inhabitants of flowers in tropical and subtropical regions of the New World. Most of these flower-inhabiting species disperse through phoretic association with hummingbirds, although some have been collected from other bird groups and from Lepidoptera. The mites are typically carried in the nares of the bird. This is the second report on the systematics of these mites based on studies carried out on the island of Trinidad during the years 1975–1982 by field teams led by one of us (RKC). Three genera of Ascidae include species exhibiting flower-bird associations. We have previously reported on the two Trinidadian species belonging to the predatory genus *Lasioseius* (Naem et al. 1985). This paper will deal with species of the genus *Proctolaelaps*, while the third genus, *Rhinosciscus*, will be considered in a final report (O'Connor et al., in preparation).

Species of *Proctolaelaps* have been described from flowers in Africa (Ryke 1954, 1964) and from nectarivorous vertebrates from Australia (Domrow 1979). Fain et al. (1977a) first reported *Proctolaelaps* from the nares of hummingbirds from the New World, briefly describing four new species: *P. hunteri*, *P. kirmsei*, *P. glaucis*, and *P. belemensis*. Those authors later (Fain et al. 1977b) gave more complete descriptions of these species and described a new subspecies, *P. belemensis cyanocompsae*, from the nares of a cardinaline finch, *Passerina (=Cyanocompsa) cyanoides*. Hyland et al. (1978) gave new host and locality records for *P. kirmsei* and *P. belemensis* and described two new species, *P. mexicanus* and *P. spiralis*, the former from the nares of a tanager, *Euphonia hirundinacea*.

Fain et al. (1977b) noted that all of the New World bird-phoretic *Proctolaelaps* shared certain unique morphological characteristics, notably the reduced cheliceral dentition and the presence of a large ventral spurlike seta on femur IV of the male. These characteristics are also found in the Australian species *P. spencerae* Domrow, 1979, but not in the African flower-inhabiting *P. vanderbergi* and *P. proteae* (Ryke 1954). Fain et al. (1977b) regarded the systematic position of the hummingbird-associated *Proctolaelaps* as uncertain, noting,

We have placed all these species in the genus *Proctolaelaps* but it is quite possible that some or all belong to another perhaps undescribed genus intermediate between *Rhinosciscus* and *Proctolaelaps* (p. 127).

In his recent revision of *Proctolaelaps*, Karg (1985) made no mention of any of these New World or Australian species. In his taxonomic arrangement, in which subgenera and species groups were based on single character differences, all of the flower-inhabiting species would belong to the *pygmaeus* species group of the subgenus *Proctolaelaps* (sensu stricto).

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It might appear that the character states noted above that are shared by the New World flower-inhabiting *Proctolaelaps* and the Australian *P. spencerae* are synapomorphies, suggesting a common ancestry. However, some caution is necessary before accepting this conclusion. It should be noted that similar character states (i.e., reduced cheliceral dentition and spurs on male femora IV) are found in the ameroiseiid genus *Hattena*, a genus known previously only from the nares of nectarivorous birds (Meliphagidae) from Australia (Domrow 1979). We have obtained specimens of *Hattena cometis* Domrow, 1979, from flowers of *Castanospermum australe* in Sydney, Australia, verifying that these mites are ecologically similar to the New World flower mites. Reduction in cheliceral dentition appears to be correlated with the switch from predation to nectar-feeding in ascid and ameroiseiid mites. Similarly, male armature is a correlate of the agonistic behavior exhibited by males toward each other (Colwell 1979, 1985, 1986a). Given the obvious convergence in morphology between flower-inhabiting *Proctolaelaps* and *Hattena*, the monophyly of the flower inhabiting *Proctolaelaps* of Australia and the New World must be tested using additional characters.

The New World flower-inhabiting *Proctolaelaps* that we have examined can easily be separated into two hypothetically monophyletic groups, the "kirmsei-group," and the "belemensis-group." These species groups are diagnosed below.

Observations on the ecology, behavior, and host associations of flower-inhabiting *Proctolaelaps* have been given by Colwell (1979, 1985, 1986a, 1986b), Dobkin (1984, 1985), and Heyneman et al. (1990). Because completion of our taxonomic studies on the Trinidad flower mites has lagged behind publication of ecological and behavioral studies, some species names have previously appeared as nomina nuda (Dobkin 1985, Colwell 1986a, 1986b, Heyneman et al. 1990). These names are validated here.

#### METHODS AND MATERIALS

Field studies were carried out during the period 1975–1982 at a variety of sites in Trinidad's Northern Range. The range consists of several parallel mountainous ridges

that form valleys oriented primarily in a north-south direction. The mountains reach about 1000 m in height. From east to west, the principal valleys from which our collections were made are the Arima, Guanapo, Aripo, and Oropuche valleys. The last contains localities from which mites had been previously collected by T. H. G. Aitken from 1954 to 1966 (Fain et al. 1977b). Most of our collecting efforts were concentrated in the Arima Valley along the Arima and Blanchisseuse roads; the latter runs through the Northern Range to the north coastal town of Blanchisseuse. Many collections were made near the Simla Research Station, owned and operated by the Asa Wright Nature Center, at 200 m elevation in the Arima Valley. The habitat is humid montane seasonal tropical rain forest with annual rainfall of 100–250 cm. The dry season occurs from January to April, the wet season from May until December. Although there are several government-managed forest reserves in the Northern Range, pristine or mature areas of forest are rare. Our collection sites were often in these forest reserves, which were largely secondary growth or under cultivation by individual farmers. Agricultural methods include slash-and-burn techniques, and during dry years extensive areas of the valleys are burned. The most disturbed areas occurred in the eastern valleys.

Most of the hummingbird-pollinated plants from which mites were collected (all indigenous species) thrive in secondary and disturbed habitats. Our collections from host plants and from birds were therefore primarily from roadsides, disturbed habitats bordering small farms, and secondary tropical rain forest. Few collections were made in mature rain forest. One additional collecting locality, Waller Field, lies 11.6 km southeast of the Simla station. This site was once a lowland (30 m) tropical rain forest but is largely secondary habitat now. A few patches of rain forest persist there, but the area is mostly young trees, shrubs, and herbs. This area, an abandoned military air field, is favorable for many of the species of plants harboring flower mites. Further descriptions of the habitats can be found in references in Dobkin (1985).

In the field, flowers or flower bracts were removed from the plant and placed in individual vials of 70% ethanol. Additional specimens were collected from hummingbird

hosts by capturing the birds in mist nets and aspirating the mites from the nares. Birds were identified and released. Mites were cleared and mounted in Hoyer's medium in the laboratory.

Our specimens were compared with the holotypes of named species in the laboratory of Dr. Alex Fain in Antwerp, Belgium. It should be noted that the holotypes of species described by Fain et al. (1977a) were stated to have been deposited in the U.S. National Museum of Natural History in Washington. Through the courtesy of Dr. Fain, one of us (BMOC) was able to study these specimens in Dr. Fain's laboratory in 1983. According to Mr. Robert Smiley, Systematic Entomology Laboratory, USDA (personal communication, 1990) the specimens have not been received by the National Museum and are presumably still in the collection of Dr. Fain.

Types and voucher specimens from our studies are deposited in the following institutions: University of Michigan Museum of Zoology, Ann Arbor, Michigan (UMMZ); Life Science Museum, Brigham Young University, Provo, Utah (BYU); U.S. National Museum of Natural History, Washington, D.C. (NMNH); Canadian National Collection of Arthropods, Biosystematics Research Centre, Ottawa, Ontario, Canada (CNC); L'Institut Royal des Sciences Naturelles, Brussels, Belgium (IRSNB).

In the following descriptions, all measurements are given in micrometers ( $\mu\text{m}$ ). For new species, measurements are given as follows: holotype, mean (range) (number of specimens measured). For the other sex and for previously described species, measurements are given as mean (range) (number of specimens measured). For each species, 10 individuals of each sex including individuals from all host plants were measured when available.

#### SPECIES ACCOUNTS

##### *The Proctolaelaps kirmsei* group

The *Proctolaelaps kirmsei* group may be diagnosed by the narrow rows of deutosternal teeth and the modification of certain leg setae in the male: the three ventral setae of femur II are enlarged and spinelike; the enlarged seta of femur IV is partially fused to a cuticular projection of the segment; and setae av1-2, pv1-2, and mv of tarsus II, seta avI of genu

IV, and setae avI and pvI of tibia IV all share a unique structure. The bases of these setae are inflated ventrally, with the filiform part of the seta projecting from the base at an angle. Narrow deutosternal tooth rows occur in some nonflower-inhabiting *Proctolaelaps*, but the modifications of the male legs are unique synapomorphies not occurring in any other *Proctolaelaps* species. Modification of some setae of tarsus II in the male is known in the genus (e.g., *P. subcorticalis* Lindquist, 1971); however, the particular form of the setae in these flower mites is unique. Described species having this set of derived characters include *P. kirmsei* and *P. glaucis*. Published descriptions of *P. hunteri* and *P. mexicanus* mention or illustrate the partially fused seta and tubercle of femur IV and the spinelike setae ventrally on femur II, and mention the presence of "spines" on tarsus II, but the text and figures are not specific as to the form or homology of the "spines." We regard these species as also belonging to this group, pending reexamination of the tarsal setation. Five species belonging to this group were collected in Trinidad: *P. kirmsei*, *P. glaucis*, and three new species.

*Proctolaelaps kirmsei* Fain, Hyland and Aitken, 1977

*Proctolaelaps kirmsei* Fain, Hyland and Aitken, 1977a: 185

*Proctolaelaps kirmsei* Fain, Hyland and Aitken, 1977b: 131

*Proctolaelaps kirmsei* Hyland, Fain and Moorhouse 1978: 263

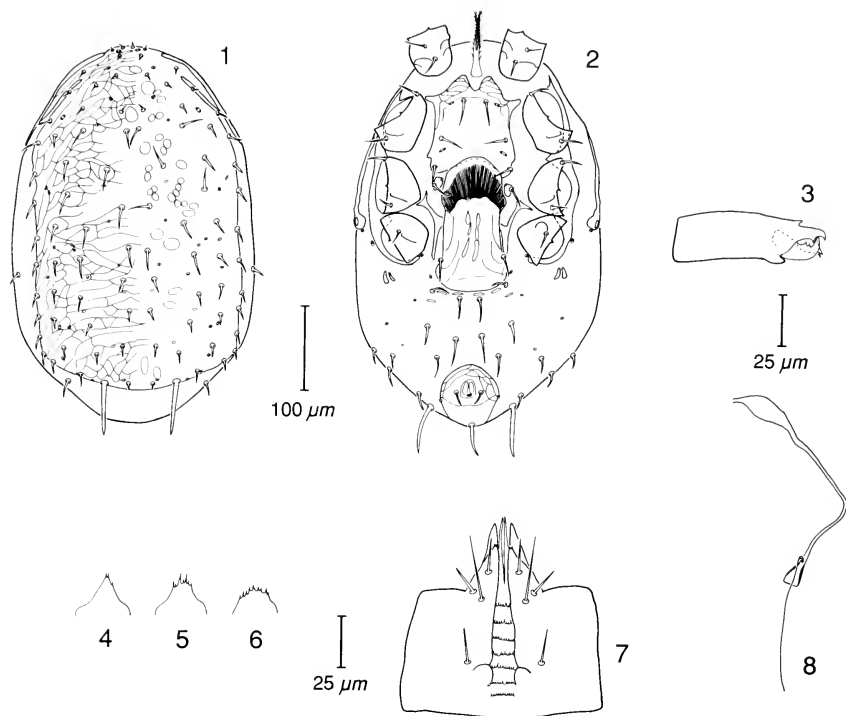
*Proctolaelaps kirmsei* Colwell, 1985: 59

*Proctolaelaps kirmsei* Colwell, 1986a: 408

*Proctolaelaps kirmsei* Colwell, 1986b: 485

*Proctolaelaps kirmsei* Heyneman et al., 1990: 458

This species was briefly diagnosed from a male and a female specimen collected from the nares of *Phaethornis augusti* from Birongo, Venezuela (Fain et al. 1977a). Fain et al. (1977b) provided some additional measurements and a figure of the male. They noted that all female specimens were in poor condition. Hyland et al. (1978) reported a single female from *Phaethornis superciliosus* from Veracruz, Mexico. Detailed observations on the ecology and host-plant associations of this species in Trinidad have been presented by Colwell (1985, 1986a) and Heyneman et al. (1990). We give here a complete description and figures of both sexes based on our Trinidad material. Our specimens were compared with the holotype.



Figs. 1-8. *Proctolaelaps kirmsei*, female: 1, dorsum; 2, venter; 3, chelicera; 4-6, variation in tectum form; 7, subcapitulum, ventral view; 8, spermathecal system.

**FEMALE** (Figs. 1-8).—Idiosomal length 483 (450-509), width 308 (287-322); dorsal shield length 452 (410-486), width 276 (252-304) ( $n = 10$ ). Dorsal shield (Fig. 1) with reticulate pattern over entire surface. Dorsal shield with 44 pairs of smooth, simple setae; marginal setae r2-r6 and R1-R6 on edge of shield, R7 on membrane posterior to shield; 3 pairs of submarginal setae (UR) on lateral membrane posterior of coxae IV. The following measurements of dorsal setae were taken from the figured specimen, a mite of average body size: setae j1-4, z1-3, and s1-2 very short (7-11 μm), setae j5-6, z4-6, and s3-6 distinctly longer (22-29 μm), anterior marginal setae (r2-6) intermediate in length (13-18 μm); posterior half of shield with J1 (24 μm) longer than other setae, most of which are approximately 13 μm long, exceptions are

the very short J5 (6 μm) and the large, stout Z5 (68 μm). Glands, proprioceptors, and muscle scars positioned as indicated in Figure 1.

Venter (Fig. 2) with tritosternum with elongate base and slender, tapering, pilose laciniae. Sternal shield longer than wide, with 3 pairs of setae and 2 pairs of pores, anterior lobes of shield well developed, with distinct linear pattern. Fourth pair of sternal setae and 3rd pair of sternal pores on metasternal platelets. Genital shield with linear ornamentation, shield slightly widened behind genital setae. Four to six small sclerites positioned directly posterior to genital shield. Endopodal apodemes distinct between epigynial shield and coxae III-IV; exopodal sclerites extending from between coxae I-II to behind coxae IV. Two pairs of small, elongate metapodal plates. Anal shield ovoid, longer than

wide (average length 84  $\mu\text{m}$ , width 76  $\mu\text{m}$ ), ornamentation confined to anterior two-thirds, postanal seta slender, about twice as long as paraanal setae. Posterior ventral region with 8 pairs of setae (Jv1-5, Zv1-3), Jv1 and Jv2 typically longer than other anterior setae, Jv5 stout and 60-70  $\mu\text{m}$  long; posterior submarginal setae (UR) also typically visible ventrally (Fig. 2). Peritreme extending anteriorly to a point approximating base of dorsal seta z1. Spermathecal system consisting of a broad, membranous pouch just inside external opening, connecting with an adductor canal approximately 90  $\mu\text{m}$  long; a small, bell-shaped maturation pouch lies at juncture of adductor canal and the long, thin spermiduct (Fig. 8).

Gnathosoma with tectum variably shaped, ranging from triangular with few teeth to broad and strongly toothed (Figs. 4-6). Chelicera with fixed digit bidentate; movable digit also bidentate with strong distal hook; a large, membranous process bearing 2 distal teeth present on paraxial face (Fig. 3). Deutosternum with 7 transverse rows of denticles; anterior 6 rows connected; no rows widened (Fig. 7). Rostral setae simple, slender, with internal posterior rostral setae at least twice as long as external posterior rostral setae; capitular setae slender, simple. Corniculi parallel; internal malae very thin, extending to or slightly beyond tip of corniculi. Palps similar to other *Proctolaelaps* species.

Legs I-IV (excluding pretarsi) 93, 73, 74, and 92% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxae II and III with pronounced convex boss, coxa IV with a weaker boss. Setation of genua of legs I, II, III, and IV, respectively, 13-11-9-9, that of tibia: 13-10-8-10; all leg setae setiform to filiform except the following spinelike setae: pd2 of femur II, ad1 of femur III, ad1 and ad2 of femur IV, and v of femur IV, which is strong and about as long as the segment width.

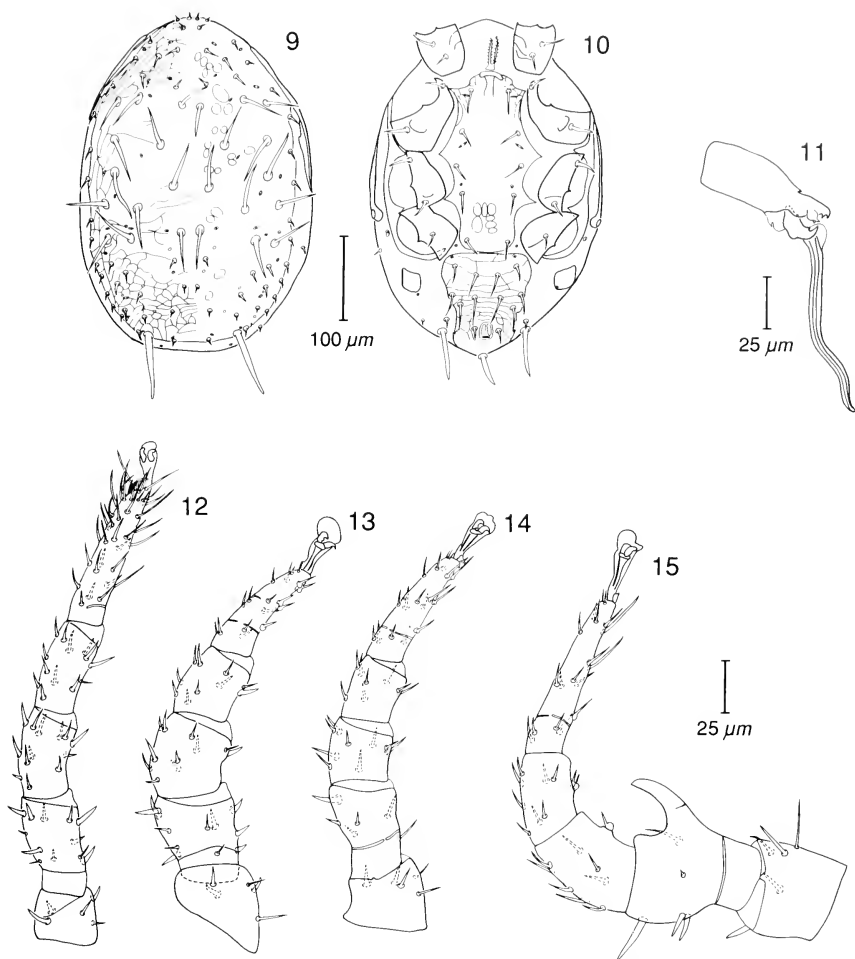
MALE (Figs. 9-15).—Idiosomal length 404 (382-422), width 281 (246-298) ( $n = 10$ ). Reticulate pattern present on anterior and posterior quarters and laterally on shield, central half of shield with pattern very weak or absent (Fig. 9). Shield with 43-45 pairs of setae, posterior marginal (R) setae varying from 5 to 7 pairs, all on shield. One pair of submarginals (UR1) laterad of coxae IV. Ante-

rior dorsal setae j1-4, z1-3, s1-2 very short (10-15  $\mu\text{m}$ ); central dorsal setae j5-6 and J1, z4-6 and Z1, s3-6 and S1 are strong spines 45-55  $\mu\text{m}$  long; posterior dorsal setae (except Z5) also short (10-15  $\mu\text{m}$ ), Z5 is a thickened, blunt spine, 75-80  $\mu\text{m}$  long; all marginal setae short. Glands, proprioceptors, and muscle scars as shown in Figure 9.

Venter (Fig. 10) with tritosternum with base distinctly shorter than in female. Sternogenital shield with reticulation confined to anteriolateral corners, smooth medially and posteriorly, with 5 pairs of setae and 3 pairs of pores. Metapodal plates quadrate, much larger than in female. Ventrianal shield relatively narrow, not extending to metapodal plates, reticulated over entire surface, with 5 pairs of ventral setae on shield, Jv1-3, Zv1-2, in addition to paraanal setae. Three pairs of ventral setae (Jv4, Jv5, and Zv3) on membrane. Setae Jv1, Jv2, Jv3, and Zv2 relatively long and setiform (28-35  $\mu\text{m}$ ), Zv1 setiform and somewhat shorter (21  $\mu\text{m}$ ); Jv4 and Zv3 microsetae (7-9  $\mu\text{m}$ ), and Jv5 a thick, blunt spine, 50-65  $\mu\text{m}$  long. Paraanal setae approximately half as long as thick, blunt postanal seta (30-40  $\mu\text{m}$ ). Peritremes much shorter than in female, extending anteriorly to the vicinity of seta s1. Endopodal apodemes fused to sternogenital shield; exopodal sclerites well developed laterad of coxae.

Gnathosoma with tectum simpler than in female, broadly rounded and with few or no teeth. Fixed digit of chelicera with one tooth and a bidentate, membranous process as in female; movable digit unidentate, with long, somewhat sinuous spermatodactyl projecting posteriorioventrally, 97-106  $\mu\text{m}$  long (Fig. 11). Corniculi shorter and stouter than in female, widely spread basally; other features of gnathosoma as on female.

Legs I-IV (excluding pretarsi) 92, 77, 72, and 97% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxa II with pronounced convex boss, coxa III with a weaker boss, coxa IV without boss. Leg I generally similar to female except some setae of femur slightly more spinelike. Leg II distinctly thickened, setae ad1, pd2, and all three ventral setae in the form of thick spines; genu and tibia each with seta pv a thick spine; tarsus with setae av1-2, pv1-2, and mv with thickened, bulbous base. Leg III with setation generally similar to female but with



Figs. 9–15. *Proctolaelaps kirmsei*, male: 9, dorsum; 10, venter; 11, chelicera; 12, leg I, dorsal view; 13, leg II; 14, leg III; 15, leg IV.

tarsal setae av1–2, pv1–2, and mv modified as on leg II. Leg IV strongly modified; femur enlarged, with ventral apophysis bearing partially fused, spurlike ventral seta, dorsal setae thickened and spinelike, especially ad1; genu with ventral seta with bulbous base; tibia with ventral setae av and pv likewise modified; tarsus with seta mv with bulbous base, setae av1 and av2 distinctly longer than pv1 and pv2. Pretarsi relatively long.

**MATERIAL EXAMINED.**—The following specimens were examined from the listed host plants in Trinidad: ex *Hamelia patens* Jacques (Rubiaceae), Arima Valley, Davis Road near Temple Village, 27 August 1980, D. S. Dobkin (#96) (31 females, 17 males); same data (#90) (1 female); same data (#89) (3 females, 2 deutonymphs); Andrews Trace, 10 mi N Arima, 21 February 1976, R. K. Colwell (#U53) (4 females); same locality, 23 February

1976, R. K. Colwell (#U54) (1 male); ex *Palicourea crocea* (Sw.) R. & S. (Rubiaceae), Arima Valley, Temple Village, dirt road near Cricket Pitch, 21 February 1979, R. K. Colwell (#T248) (1 male); Blanchisseuse Road, mile 9, 24 August 1980, D. S. Dobkin (#43) (3 females); same data, (#44), (#45) (numerous specimens); ex *Psiguria tryphylla* (Miq.) C. Jeffrey (Cucurbitaceae), Arima Valley, 50 m S Scott's Quarry, 17 February 1979, R. K. Colwell (#T219) (1 female, 2 males); ex *Costus scaber* Ruiz & Pavón (Zingiberaceae), Blanchisseuse Road, mile 19, 11 March 1979, R. K. Colwell (#T247) (2 females).

Specimens collected from hummingbirds include the following phoretic hosts: ex *Amazilia chionopectus chionopectus* (Gould), Arima Valley, Simla, 15–18 February 1976, R. K. Colwell (#U1, U2) (4 females); ex *Amazilia tobaci erythronotos* (Lesson), Arima Valley, Simla, 21–24 July 1975, R. K. Colwell (#T41, T42, T43) (7 females, 2 males); same locality, 15 February 1976, R. K. Colwell (#U11, U16) (4 females, 3 males); Arima Valley, Lower La Laja Trace, 23–24 February 1976, R. K. Colwell (#U12, U13, U15) (9 females, 2 males); ex *Chlorestes notatus notatus* (C. Reichenbach), Andrews Trace, 2 August 1975, R. K. Colwell (#T17) (1 female); Arima Valley, Simla, 30 July–2 August 1975, R. K. Colwell (#T24, T40) (5 females); Lower La Laja Trace, 24 February 1976, R. K. Colwell (#U9) (2 females); Arima Valley, Simla, 18–20 February 1976, R. K. Colwell (#U4, U5) (2 females); ex *Glaucis hirsuta insularum* Hellmayr and Seilern, La Laja Trace, 11 August 1975, R. K. Colwell (#T44) (1 female); Arima Valley, Simla, 24 July 1975, R. K. Colwell (#T50) (6 females); same locality, 15–20 February 1976, R. K. Colwell (#U22, U23, U25, U27, U29, U34, U38, U43, U44, U45, U46, U47) (64 females, 26 males); ex *Phaethornis guy guy* (Lesson), Andrews Trace, 30 December 1973, R. K. Colwell (#T36) (6 females); Arima Valley, Simla, 18 February 1976, R. K. Colwell (#U17) (1 female).

**SPECIMEN DEPOSITION.**—Voucher specimens are deposited in the following institutions: UMMZ, NMNH, BYU, CNC.

**COMMENTS.**—Our specimens agree closely with the descriptions given by Fain et al. (1977b) except that the anterior pair of sternal setae in the female are more widely spaced

as in other members of the *kirmsei*-group (26–31  $\mu\text{m}$  vs. 21  $\mu\text{m}$  as given by Fain et al.). Colwell (1986a, 1986b) and Heyneman et al. (1990) have noted the seasonal shift in primary host plants exhibited by this species. The preferred host plant in the wet season is *Hamelia patens*, while *Palicourea crocea* is used preferentially in the dry season. It should be noted that our specimens collected during the wet season averaged slightly larger than specimens taken during the dry season. As the type-series was collected during the dry season, the somewhat larger average measurements given above for the species as a whole are explained by the inclusion of wet-season individuals.

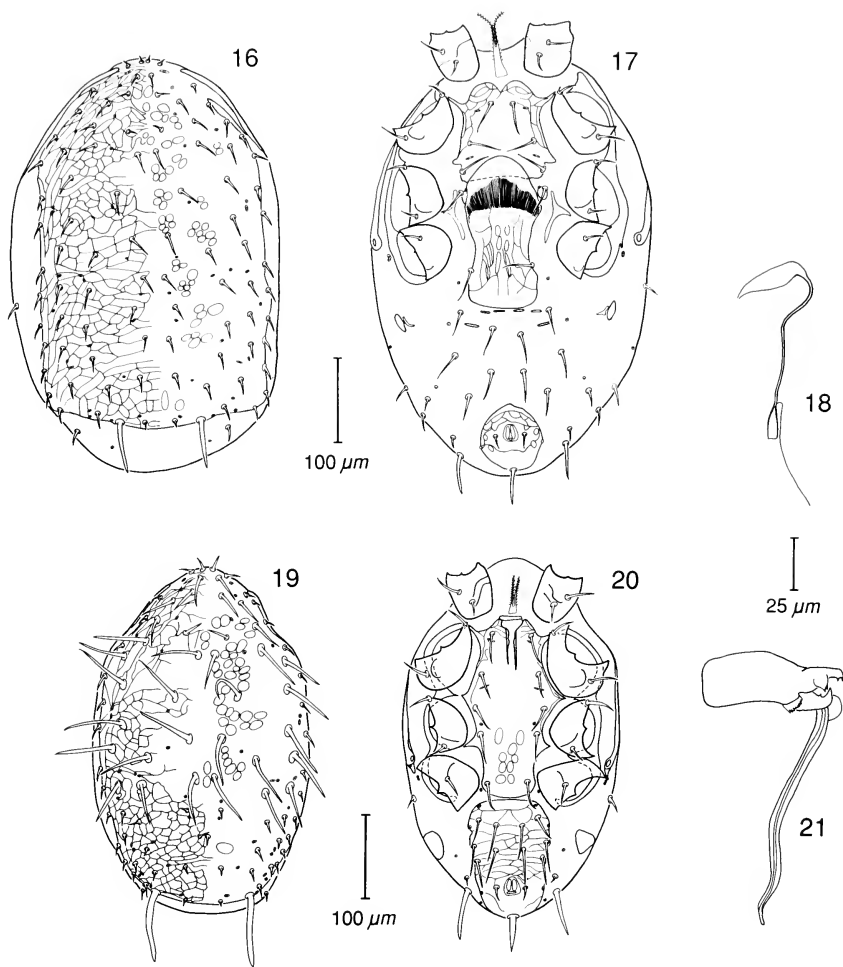
*Proctolaelaps jurgatus*, new species

*Proctolaelaps jurgatus* Colwell, 1986: 408, nomen nudum

*Proctolaelaps jurgatus* Heyneman et al., 1990: 468, nomen nudum

**FEMALE** (Figs. 16–18).—Idiosomal length 599, 536 (486–631), width 363, 332 (291–383); dorsal shield length 478, 453 (416–485), width 284, 265 (247–285) ( $n = 10$ ). Dorsal shield (Fig. 16) with reticulate pattern over entire surface. Dorsal shield with 44 pairs of smooth, simple setae; marginal setae r2–6 and R1–6 on edge of shield, R7 on membrane posterior to shield, an additional marginal seta (r1) occasionally present unilaterally as on holotype; 3 pairs of submarginal setae (UR) on lateral membrane posteriad of coxae IV. The following measurements of dorsal setae were taken from the holotype, a mite of somewhat larger than average body size: setae j1, j4, and z1 very short (9–11  $\mu\text{m}$ ), setae j2–3, z3, s1–2 longer (15–18  $\mu\text{m}$ ), other anterior setae longer (22–29  $\mu\text{m}$ ); posterior half of shield with anterior median setae J1, Z1, and S1 longer (20–24  $\mu\text{m}$ ) than most other setae (15  $\mu\text{m}$ ), J5 a microseta (9  $\mu\text{m}$ ) and Z5 a stout, elongate spine (64  $\mu\text{m}$ ); all marginal setae 15–22  $\mu\text{m}$  long. Glands, proprioceptors, and muscle scars positioned as indicated in Figure 16.

Venter (Fig. 17) with tritosternum with elongate base and slender, tapering, pilose laciniae. Sternal shield longer than wide, with 3 pairs of relatively long setae and 2 pairs of pores, lengths of setae greater than or equal to distance between st2 and st3; anterior lobes and lateral margins of shield with distinct linear pattern. Fourth pair of sternal setae and 3rd pair of sternal pores on metasternal



Figs. 16–21. *Proctolaelaps jurgatus*: 16, female dorsum; 17, female venter; 18, female spermathecal system; 19, male dorsum; 20, male venter; 21, male chelicera.

platelets. Genital shield with linear ornamentation, shield widened behind genital setae. Six small sclerites positioned directly posterior to genital shield. Endopodal apodemes distinct between epigynial shield and coxae III–IV; exopodal sclerites extending from between coxae I–II to behind coxae IV. Two pairs of small, elongate metapodal plates.

Anal shield ovoid, longer than wide (length 87, 81 [74–94], width 77, 73 [65–79]  $\mu\text{m}$ ), ornamentation confined to anterior two-thirds, postanal seta slender, about twice as long as paraanal setae. Posterior ventral region with 8 pairs of setae (JV1–5, Zv1–3), Jv1 and Jv2 typically longer than other anterior setae, Jv5 stout and 53  $\mu\text{m}$  long in holotype;

posterior submarginal setae (UR) also typically visible ventrally (Fig. 17). Peritreme extending anteriorly to a point between bases of dorsal setae *z1* and *s1*. Spermathecal system consisting of a broad, membranous pouch just inside external opening, connecting with an adductor canal approximately 65–70  $\mu\text{m}$  long; a small, elongate, bell-shaped maturation pouch lies at juncture of adductor canal and the long, thin spermiduct (Fig. 18).

Gnathosoma with tectum variably shaped as in *P. kirmsei*. Chelicera with fixed digit bidentate; movable digit also bidentate with strong distal hook; a large, membranous process bearing 2 distal teeth present on paraxial face. Deutosternum with 7 transverse rows of denticles; anterior 6 rows connected; no rows widened. Rostral setae simple, slender, with internal posterior rostral setae at least twice as long as external posterior rostral setae; capitular setae slender, simple. Corniculi parallel; internal malae very thin, extending to or slightly beyond tip of corniculi. Palps similar to other *Proctolaelaps* species.

Legs I–IV (excluding pretarsi) 81, 72, 73, and 86% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxae II and III with pronounced convex boss, coxa IV with a weaker boss. Setation of genua of legs I, II, III, and IV, respectively, 13-11-9-9, that of tibia: 13-10-8-10; all leg setae setiform to filiform except the following spinelike setae: *ad1*, *ad3*, *pd1*, *pd2* of femur I, *pd2* of femur II, *ad1* of femur III, *ad1* and *ad2* of femur IV; setae *all* and *v* of femur IV are setiform, but elongate, about as long as the segment width.

MALE (Figs. 19–21).—Idiosomal length 420 (391–432), width 271 (252–281) ( $n = 10$ ). Reticulate pattern present laterally on shield and on posterior third; central half of shield with pattern very weak or absent (Fig. 19). Shield with 43–45 pairs of setae, posterior marginal (R) setae varying from 5 to 7 pairs, all on shield; anterior marginal seta *r1* occasionally unilaterally present as on figured specimen. One pair of submarginals (UR1) laterad of coxae IV. Anterior dorsal setae of *j*, *z*, and *s* series all spinelike; the following measurements of dorsal setae are taken from the figured specimen: *j1*–17, *j2* and *j3*–42, *j4*–26, *j5*–57, *j6*–68, *z1*–11, *z2*–35, *z3*–44, *z4*–64, *z5*–57, *z6*–64, *s1*–15, *s2*–20, *s3*–57, *s4*, *s5* and *s6* all 66  $\mu\text{m}$ ; all anterior marginal setae 15–20  $\mu\text{m}$

long. Posterior dorsal setae *J1*, *Z1*, and *S1* also long. Posterior spines, 68, 64, and 55  $\mu\text{m}$  long; terminal seta *Z5* is a thickened, blunt spine, 92  $\mu\text{m}$  long; other posterior dorsal and marginal setae very short (10–15  $\mu\text{m}$ ). Glands, proprioceptors, and muscle scars as shown in Figure 19.

Venter (Fig. 20) with tritosternum with base distinctly shorter than in female. Sternogenital shield with reticulation confined to anteriolateral corners, smooth medially and posteriorly, with 5 pairs of setae and 3 pairs of pores. Metapodal plates triangular to quadrate, much larger than in female. Ventrianal shield relatively narrow, not extending to metapodal plates, reticulated over entire surface, with 5 pairs of ventral setae on shield, *Jv1*–3, *Zv1*–2, in addition to paraanal setae. Three pairs of ventral setae (*Jv4*, *Jv5*, and *Zv3*) on membrane, *Zv3* strongly displaced dorso-laterally. Setae *Jv1*, *Jv2*, *Jv3*, and *Zv2* relatively long and setiform (40–45  $\mu\text{m}$ ), *Zv1* setiform and somewhat shorter (29  $\mu\text{m}$ ); *Jv4* and *Zv3* short (10–11  $\mu\text{m}$ ), and *Jv5* a thick, blunt spine, 60–70  $\mu\text{m}$  long. Paraanal setae approximately half as long as thick, blunt postanal seta (35–45  $\mu\text{m}$ ). Peritremes much shorter than in female, extending anteriorly to the vicinity of seta *s1*. Endopodal apodemes fused to sternogenital shield; exopodal sclerites well developed laterad of coxae.

Gnathosoma with tectum simpler than in female, broadly rounded and with few or no teeth. Fixed digit of chelicera with one tooth and a bidentate, membranous process as in female; movable digit unidentate, with long, somewhat sinuous spermatodactyl projecting posteroventrally, 114–125  $\mu\text{m}$  long (Fig. 21). Corniculi shorter and stouter than in female, widely spread basally; other features of gnathosoma as on female.

Legs I–IV (excluding pretarsi) 83, 69, 65, and 92% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxa II with pronounced convex boss, coxa III with a weaker boss, coxa IV without boss. Leg I generally similar to female except some setae of femur distinctly more spinelike. Leg II distinctly thickened, setae *ad1*, *pd2*, and all three ventral setae in the form of thick spines; genu and tibia each with seta *pv* a thick spine; tarsus with setae *av1*–2, *pv1*–2, and *mv* with thickened, bulbous base. Leg III with setation generally similar to female but with tarsal setae *av1*–2, *pv1*–2, and *mv* modified as



on leg II. Leg IV strongly modified; femur enlarged, with ventral apophysis bearing partially fused, spurlike ventral seta, dorsal setae thickened and spinelike especially ad1; genu with ventral seta with bulbous base; tibia with ventral setae av and pv likewise modified; tarsus with seta mv with bulbous base, setae av1 and av2 distinctly longer than pv1 and pv2. Pretarsi relatively long.

ETYMOLOGY.—The specific name *jurgatus* is from the Latin meaning "quarrelsome" and is an adjective.

MATERIAL EXAMINED.—All specimens from host plants were collected from the flowers of *Iserbia parviflora* Vahl. (Rubiaceae) from the following Trinidad localities (all examined specimens are considered paratypes): Arima Valley, Cricket Pitch near Temple Village, 12 March 1979, R. K. Colwell (#T280) (holotype and 2 other females, 4 males); same data (#T281) (1 female, 2 males, 1 deutonymph); same locality, 23 February 1979, R. K. Colwell (#T242) (1 female); same data (#T240) (2 females); Arima Valley, Temple Village, 11 August 1975, R. K. Colwell (#T74) (3 females); Waller Field, 22 February 1976, R. K. Colwell (#U66) (1 male); Waller Field, near entrance, 21 March 1979, R. K. Colwell (#T622) (10 females, 5 males, 4 deutonymphs); same data (#T620, T621, T622) (a large series of specimens).

Specimens collected from hummingbirds include the following phoretic hosts: ex *Amazilia tobaci erythronotos* (Lesson), Waller Field, 23 June 1976, P. Feinsinger (#W2, W3, W4) (21 females); ex *Chlorestes notatus notatus* (C. Reichenbach), Lower La Laja Trace, 23 February 1976, R. K. Colwell (#U8) (1 female); ex *Chrysolampis mosquitus* (Linne), Waller Field, 23 June 1976, P. Feinsinger (#W5, W6, W7, W8, W9) (48 females, 5 males); ex *Phaethornis longuemareus longuemareus* (Lesson), Waller Field, 23 June 1976, P. Feinsinger (#W10, W11, W12, W13) (2 females, 2 males).

SPECIMEN DEPOSITION.—Holotype and paratypes in UMMZ, additional paratypes in NMNH, BYU, CNC, and IRSNB.

COMMENTS.—This species is most closely related to *P. kirmsei*, sharing with that species the derived character states of a bell-shaped maturation pouch in the female spermathecal system and the enlarged central setae of the male dorsum. With respect to other members

of the *kirmsei*-group, this species manifests the ancestral conditions of retaining metasternal platelets in the female, retaining dorsal seta z3 in both sexes, having posterior setae z5 and Jv5 simple (not clubbed) spines, and having all marginal setae (except R7) on the dorsal shield.

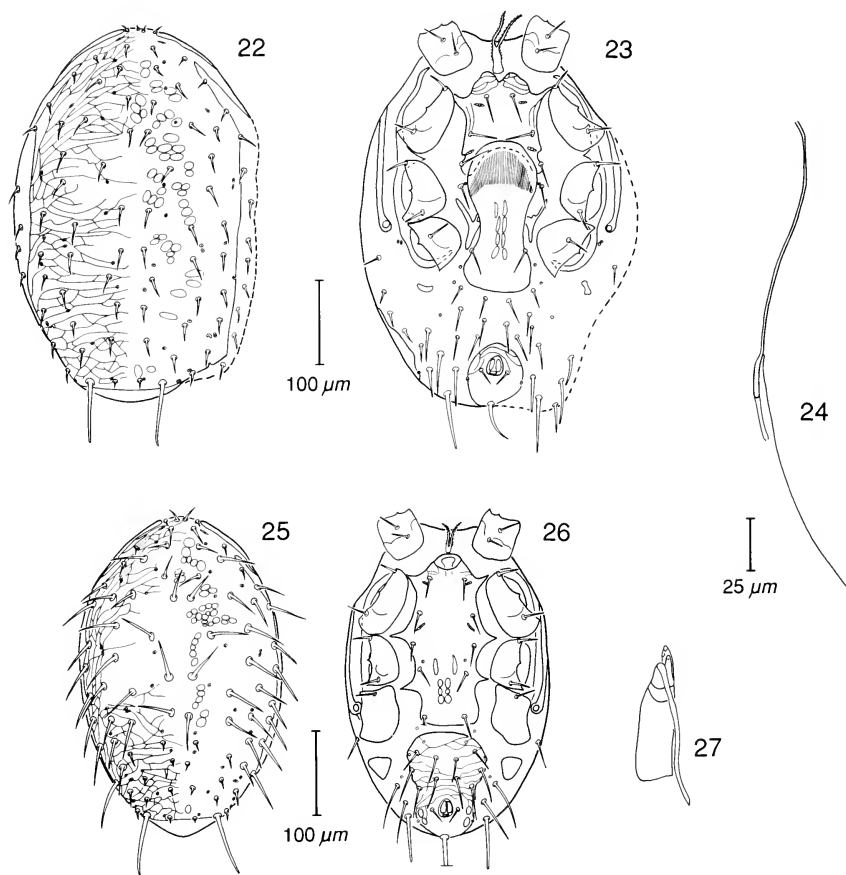
*Proctolaelaps jurgatus* may be distinguished from *P. kirmsei* in the female by the relatively longer sternal setae, longer maturation pouch in the spermathecal system, and relatively shorter posterior seta Jv5; and in the male by the much greater size of the anterior dorsal setae, especially j1–3, z2–3, and s3.

*Proctolaelaps mermillion*, new species

*Proctolaelaps mermillion* Colwell, 1986a: 408, nomen nudum

FEMALE (Figs. 22–24).—The following description is of the holotype and only known female. Idiosomal length 468, width 301  $\mu$ m; dorsal shield length 456, width 263  $\mu$ m. Dorsal shield (Fig. 22) with reticulate pattern over entire surface. Dorsal shield with 34 pairs of smooth, simple setae; seta z3 absent; marginal setae r2–3 on shield, other anterior marginals (r4–6) and posterior marginals (R1–7) on membrane lateral to shield (R5 unilaterally absent); 3 pairs of submarginal setae (UR) on lateral membrane posteriad of coxae IV. All setae setiform except Z5, which is an elongate, blunt spine. Setal lengths as follows: j1–6, 7, 11, 13, 15, 18, 22  $\mu$ m; z1–6 (z3 absent), 7, 20, x, 22, 20, 20  $\mu$ m; s1–6, 11, 11, 18, 23, 24, 22  $\mu$ m; posterior half of shield with J1–5, 22, 20, 19, 20, 8  $\mu$ m; Z1–5, 22, 22, 20, 19, 77  $\mu$ m; S1–5, 18, 18, 15, 15, 15  $\mu$ m; all marginal setae 13–15  $\mu$ m long except R7, which is more spinelike and 33  $\mu$ m long. Glands, proprioceptors, and muscle scars positioned as indicated in Figure 22.

Venter (Fig. 23) with tritosternum with elongate base and slender, tapering, pilose laciniae. Sternal shield longer than wide, with distinctly concave posterior border, bearing 3 pairs of setae and 2 pairs of pores; anterior lobes of shield well developed, with distinct linear pattern. Fourth pair of sternal setae and 3rd pair of sternal pores on membrane posterior to shield; metasternal platelets absent. Genital shield without linear ornamentation, shield distinctly widened behind genital setae. No small sclerites observed posterior



Figs. 22–27. *Proctolaelaps mermillon*: 22, female dorsum; 23, female venter; 24, female spermathecal system; 25, male dorsum; 26, male venter; 27, male chelicera.

to genital shield. Endopodal apodemes distinct between epigynial shield and coxae III–IV; exopodal sclerites extending from between coxae I–II to behind coxae IV. One pair of small, elongate metapodal plates. Anal shield ovoid, longer than wide, ornamentation confined to anterior half, postanal seta slender, about twice as long as paraanal setae. Posterior ventral region with 8 pairs of setae (Jv1–5, Zv1–3) and a supernumerary Zv seta unilaterally; lengths of setae as follows: Jv1–5, 26, 35, 35, 46, 68  $\mu\text{m}$ ; Zv1–3, 20, 31, 29  $\mu\text{m}$ ;

setae setiform to filiform except Jv4–5 and two posterior UR setae, which are thickened spines, the latter being 37 and 48  $\mu\text{m}$  long. Peritreme extending antieriad to a point approximating base of dorsal seta z1. Spermathecal system lacking expanded, membranous pouch inside opening, system consisting of a narrow adductor canal approximately 117  $\mu\text{m}$  long; an elongate maturation pouch 48  $\mu\text{m}$  long, which is divided roughly in half, anterior half more strongly sclerotized; and a thin spermiduct at least 110  $\mu\text{m}$  long (Fig. 24).

Gnathosoma with tectum broadly rounded with few apical teeth. Chelicerae visible only in dorsoventral view, with fixed digit bidentate; movable digit not clearly observed. Deutosternum with 7 transverse rows of denticles; anterior 6 rows connected; no rows widened. Rostral setae simple, slender, with internal posterior rostral setae at least twice as long as external posterior rostral setae; capitular setae slender, simple. Corniculi parallel; internal malae not observed. Palps similar to other *Proctolaelaps* species.

Legs I–IV (excluding pretarsi) 94, 65, 77, and 96% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxae II and III with convex boss, coxa IV with a weaker boss. Setation of genua of legs I, II, III, and IV, respectively, 13-11-9-9, that of tibia: 13-10-8-10; all leg setae setiform to filiform except the following spinelike setae: ad1 of femur III, ad1 and ad2 of femur IV, and v of femur IV, which is strong and about as long as the segment width.

MALE (Figs. 25–27).—The following description is of the single available male specimen. Idiosomal length 386, width 256  $\mu\text{m}$ . Reticulate pattern present on anterior quarter and posterior half and laterally on shield, central region of shield with pattern very weak or absent (Fig. 25). Shield with 41 pairs of setae, z3 absent, only 3 pairs of posterior marginal (R) setae present, all on shield. One pair of submarginals (UR1) laterad of coxae IV. Many dorsal setae elongate and spinelike, lengths of setae: j1–6, 15, 20, 22, 31, 35, 44  $\mu\text{m}$ ; z1–6, 9, 42, x, 44, 45, 48  $\mu\text{m}$ ; s1–6, 11, 11, 45, 48, 53, 48  $\mu\text{m}$ ; posterior setae j1–5, 46, 9, 7, 6, 3  $\mu\text{m}$ ; Z1–5, 48, 13, 9, 9, 70  $\mu\text{m}$ ; S1–5, 44, 44, 34, 24, 11  $\mu\text{m}$ . All marginal setae elongate and spinelike, lengths of r2–6 and R1–3, 33, 51, 44, 53, 44, 48, 48, 57  $\mu\text{m}$ . Glands, proprioceptors, and muscle scars as shown in Figure 25.

Venter (Fig. 26) with tritosternum with base distinctly shorter than in female. Sternogenital shield with very weak reticulation confined to anteriolateral corners, smooth medially and posteriorly, with 5 pairs of setae and 3 pairs of pores. Metapodal plates triangular, much larger than in female. Ventrianal shield relatively narrow, not extending to metapodal plates, reticulated over entire surface, with 5 pairs of ventral setae on shield, Jv1–3, Zv1–2, in addition to paraanal setae. Three pairs of ventral setae (Jv4, Jv5, and Zv3) on

membrane. Setae Jv1–3 and Zv1–3 moderately long and setiform, lengths 33, 40, 41, 24, 42, 53  $\mu\text{m}$ ; Jv4 and Jv5 are stouter and spinelike, 53 and 57  $\mu\text{m}$  long. Paraanal setae thin, postanal seta thick, broken in specimen examined. Peritremes similar to female, extending anteriorly to the vicinity of seta z1. Endopodal apodemes fused to sternogenital shield; exopodal sclerites well developed laterad of coxae, but difficult to observe due to distortion of legs in specimen.

Gnathosoma with tectum similar to female, broadly rounded and with few teeth. Chelicerae only observed in dorsoventral view; fixed digit of chelicera with one tooth; movable digit not clearly observed, with moderately sized, slightly sinuous spermatodactyl projecting posterioventrally, 73  $\mu\text{m}$  long (Fig. 27). Corniculi shorter and stouter than in female, widely spread basally; other features of gnathosoma as on female.

Legs I–IV (excluding pretarsi) 90, 71, 71, and 97% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxa II with pronounced convex boss, coxa III with a weaker boss, coxa IV without boss. Leg I generally similar to female except some setae of femur slightly more spinelike. Leg II distinctly thickened, setae ad1, pd2, and all three ventral setae in the form of thick spines; genu and tibia each with seta pv a thick spine; tarsus with setae av1–2, pv1–2, and mv with thickened, bulbous base. Leg III with setation generally similar to female but with tarsal setae av1–2, pv1–2 and mv modified as on leg II, although setal bases are not as swollen. Leg IV strongly modified; femur enlarged, with ventral apophysis bearing partially fused, spurlike ventral seta, dorsal setae thickened and spinelike especially ad1; genu with ventral seta with bulbous base; tibia with ventral setae av and pv likewise modified; tarsus with seta mv with bulbous base, setae av1 and av2 distinctly longer than pv1 and pv2. Pretarsi relatively long.

ETYMOLOGY.—The species name *mermillion* is modified from the Greek meaning “gladiator.” It is a masculine noun in apposition.

MATERIAL EXAMINED.—Holotype female and 1 paratype male from the nares of *Amazilia chionopectus* (Trochilidae), TRINIDAD: Simla Research Station, 4 mi N Arima, 18 February 1976, R. K. Colwell (#U3).

Two additional female specimens collected from a hummingbird, *Phaethornis guy guy* (Lesson), same locality and date, R. K. Colwell (#U18), were not included in the above description and are not considered paratypes.

**SPECIMEN DEPOSITION.**—Holotype and paratype in UMMZ.

**COMMENTS.**—*Proctolaelaps mermillion* is the only species of flower mite we were unable to collect from a host plant in Trinidad. We suspect that the host of this species is an epiphyte because, while our collecting of terrestrial hummingbird-pollinated plants was exhaustive, we were unable to sample some epiphytic species.

This species is most closely related to *P. hunteri*, a species known at present only from Brazil. The two species share the derived character states of loss of dorsal seta z3 in both sexes, posterior marginal setae off the dorsal shield in the female, and the enlargement of the posterior marginal setae in the male. The species differs from *P. hunteri* in the female by the posteriorly concave sternal shield, and by having marginal setae r4–5 off the dorsal shield; male *P. mermillion* lack 4–5 pairs of posterior marginal setae that are present and elongate in *P. hunteri*, and also posterior dorsal setae S3–5 are distinctly shorter in male *P. mermillion*.

*Proctolaelaps glaucis* Fain, Hyland and Aitken, 1977

*Proctolaelaps glaucis* Fain, Hyland and Aitken, 1977a: 185

*Proctolaelaps glaucis* Fain, Hyland and Aitken, 1977b: 129

*Proctolaelaps glaucis* Colwell, 1985: 61

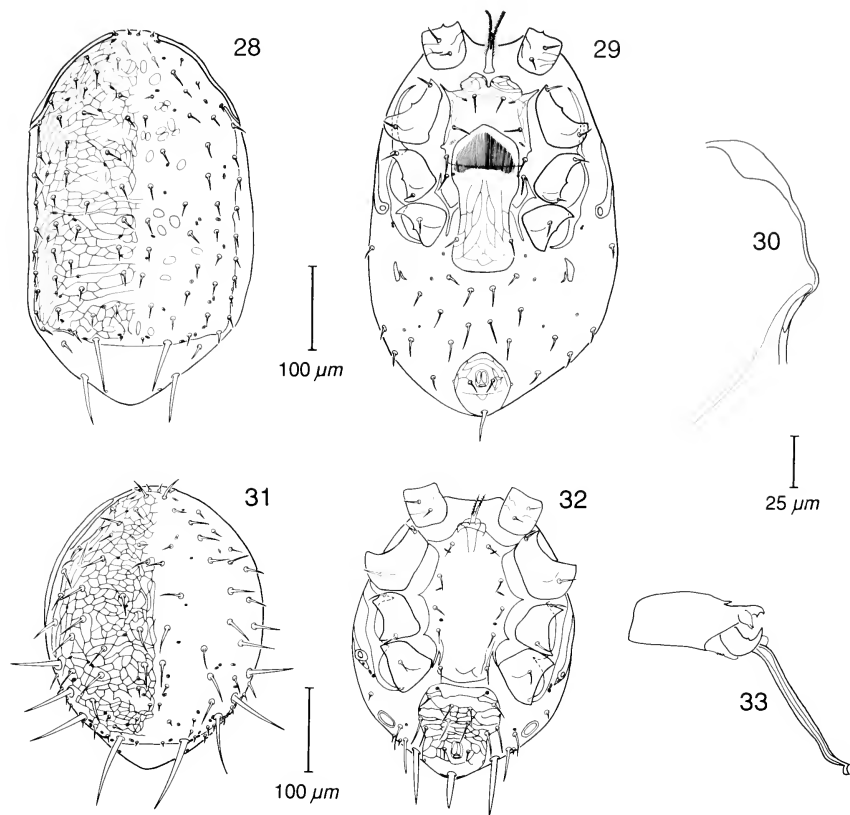
*Proctolaelaps glaucis* Colwell, 1986a: 408

This species was briefly diagnosed from the holotype female collected from the nares of *Glaucis hirsuta* from "Trinidad" (Fain et al. 1977a). Fain et al. (1977b) provided a more complete description of the female and a brief description of one male; both sexes were figured. All specimens were collected from the nares of *G. hirsuta* from the following Trinidad localities: Ravine Sable Trace—Vega de Oropouche, Esperanza Estate, Corneillac Estate, Fort Read. Some aspects of the ecology and host associations of this species have been discussed by Colwell (1985, 1986a). We give here a redescription of this species based on our collections from Trinidad. Our specimens were compared with the holotype.

**FEMALE** (Figs. 28–30).—Idiosomal length

462 (439–497), width 318 (281–369)  $\mu\text{m}$ ; dorsal shield length 400 (386–410), width 258 (246–287)  $\mu\text{m}$  ( $n = 8$ ). Dorsal shield (Fig. 28) with reticulate pattern over entire surface. Dorsal shield with 44 pairs of smooth, simple setae; marginal setae r2–6 and R1–6 on edge of shield, R7 on membrane posterior to shield; 3 pairs of submarginal setae (UR) on lateral membrane posteriad of coxae IV. The following measurements of dorsal setae were taken from the figured specimen, a mite of somewhat larger than average body size: j setae very unequal, lengths of j1–6, 8, 22, 18, 9, 18, 20  $\mu\text{m}$ ; anterior z setae also unequal, lengths of z1–6, 12, 24, 15, 22, 20, 20, 20  $\mu\text{m}$ ; s1–2 both 13  $\mu\text{m}$ , s3–6 all 20–22  $\mu\text{m}$ ; posterior dorsal setae (except J5 and Z5) and all marginal setae (r–R) 18–20  $\mu\text{m}$ , J5 very short (7  $\mu\text{m}$ ), Z5 long and spinelike (62  $\mu\text{m}$ ). Glands, proprioceptors, and muscle scars positioned as indicated in Figure 28.

Venter (Fig. 29) with tritosternum with elongate base and slender, tapering, pilose laciniae. Sternal shield longer than wide, posterior border generally straight, with 3 pairs of setae and 2 pairs of pores; anterior lobes of shield well developed, with distinct linear pattern; linear pattern also present laterally. Fourth pair of sternal setae and 3rd pair of sternal pores on membrane posterior to shield, metasternal platelets absent. Genital shield with linear ornamentation, shield slightly widened behind genital setae. Without small sclerites posterior to genital shield. Endopodal apodemes distinct between epigynial shield and coxae III–IV; exopodal sclerites extending from between coxae I–II to behind coxae IV. Two pairs of metapodal plates, external plate elongate and much larger than internal plate, which was not observed in all specimens. Anal shield wider than long (averaging 70  $\mu\text{m}$  long to 75  $\mu\text{m}$  wide), ornamentation confined to anterior two-thirds, postanal seta spinelike, about twice as long as paraanal setae. Posterior ventral region with 8 pairs of setae (JV1–5, Zv1–3, figured specimen with supernumerary Zv seta unilaterally), Jv1 and Jv2 typically longer than other anterior setae, Jv5 stout and 60–70  $\mu\text{m}$  long; posterior submarginal setae (UR) also typically visible ventrally (Fig. 29). Peritreme extending anteriorly to a point approximating base of dorsal seta z1. Spermathecal system (Fig. 30) consisting of a



Figs. 28–33. *Proctolaelaps glaucis*: 28, female dorsum; 29, female venter; 30, female spermathecal system; 31, male dorsum; 32, male venter; 33, male chelicera.

broad, membranous pouch just inside external opening, connecting with an adductor canal approximately 51  $\mu\text{m}$  long; an elongate maturation pouch 42  $\mu\text{m}$  long that is divided roughly in half, anterior half more strongly sclerotized; and a thin spermiduct at least 100  $\mu\text{m}$  long.

Gnathosoma with tectum broadly rounded with few apical teeth. Chelicerae visible only in dorsoventral view, with fixed digit bidentate and bearing a large, membranous process with two distal teeth; movable digit not clearly observed. Deutosternum with 7 transverse rows of denticles; anterior 6 rows connected; no rows widened. Rostral setae simple, slen-

der, with internal posterior rostral setae slightly less than twice as long as external posterior rostral setae; capitular setae slender, simple. Corniculi parallel; internal malae not observed. Palps similar to other *Proctolaelaps* species.

Legs I–IV (excluding pretarsi) 91, 71, 72, and 90% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxae II and III with convex boss, coxa IV with a weaker boss. Setation of genua of legs I, II, III, and IV, respectively, 13-11-9-9, that of tibia: 13-10-8-10; all leg setae setiform to filiform except the following spinelike setae: ad1 of femur III, and ad1 of

femur IV; seta v of femur IV longer than other setae but not as long as the segment width.

MALE (Figs. 31–33).—Idiosomal length 347 (316–398), width 257 (222–281) ( $n = 10$ ). Reticulate pattern present covering dorsal shield (Fig. 31). Shield with 43–44 pairs of setae, posterior marginal (R) setae varying from 5 to 7 pairs, all on shield except R7. One pair of submarginals (UR1) laterad of coxae IV. Most anterior and central dorsal setae somewhat elongate and spinelike; posterior setae mostly very short except lateral setae S2–3 and r6 and terminal seta Z5, which are very large spines. Dorsal setae exhibiting more length variation than in other species; the following measurements are from the smallest and largest measured males: j1, 7–9; j2, 20–26; j3, 18–18; j4, 11–15; j5, 24–24; j6, 29–37; z1, 7–9; z2, 24–29; z3, 15–20; z4, 26–31; z5, 29–33; z6, 29–31; s1, 10–15; s2, 11–11; s3, 24–30; s4, 30–33; s5, 31–35; s6, 26–35; r2, 13–15; r3, 22–24; r4, 20–24; r5, 24–26; r6, 35–55; posterior setae: J1, 29–37; J2, 7–11; J3, 6–9; J4, 9–9; J5, 4–5; Z1, 29–37; Z2, 29–33; Z3, 13–11; Z4, 11–11; Z5, 70–92; S1, 26–26; S2, 57–66; S3, 57–75; S4, 10–15; S5, 10–10. Posterior marginal setae all approximately 5–9  $\mu\text{m}$ , except R1, which may be somewhat longer when present. Glands, proprioceptors and muscle scars as shown in Figure 31.

Venter (Fig. 32) with tritosternum base distinctly shorter than in female. Sternogenital shield with slight linear ornamentation confined to posteriolateral corners, smooth anteriorly and medially, with 5 pairs of setae and 3 pairs of pores. Metapodal plates difficult to observe, generally hidden by enlarged femora IV; plates ovoid to quadrate, with possibly thickened margins. Ventrianal shield relatively narrow, not extending to metapodal plates, reticulated over entire surface, with 5 pairs of ventral setae on shield, Jv1–3, Zv1–2, in addition to paraanal setae. Three pairs of ventral setae (Jv4, Jv5, and Zv3) on membrane. Setae Jv2, Jv3, and Zv2 setiform and of moderate length (30–33  $\mu\text{m}$ ); Jv1, Zv1 setiform and somewhat shorter (20  $\mu\text{m}$ ); Jv4 somewhat thicker and 37  $\mu\text{m}$  long; Jv5 a thick, blunt spine, 50–55  $\mu\text{m}$  long. Paraanal setae approximately one-third as long as very thick, blunt postanal seta (38–44  $\mu\text{m}$ ). Peritremes much shorter than in female, extending anteriorly to the vicinity of seta s1. Endopodal apodemes fused to sternogenital

shield; exopodal sclerites well developed laterad of coxae.

Gnathosoma with tectum simpler than in female, broadly rounded and with few or no teeth. Fixed digit of chelicera with one tooth and a bidentate, membranous process as in female; movable digit with a rudimentary tooth, with long, somewhat sinuous spermatodactyl projecting posterioventrally, 88  $\mu\text{m}$  long (no variation); spermatodactyl with a small, apical quadrate process projecting from tip (Fig. 33). Corniculi shorter and stouter than in female, widely spread basally; other features of gnathosoma as on female.

Legs I–IV (excluding pretarsi) 98, 82, 77, and 105% of dorsal shield length. Coxa I with fine linear ornamentation medially and laterally; coxa II with pronounced convex boss, coxae III–IV with a weaker boss. Leg I generally similar to female except some setae of femur slightly more spinelike. Leg II distinctly thickened, setae ad1, pd2, and all three ventral setae in the form of thick spines; genu and tibia each with seta pv a thick spine; tarsus with setae av1–2, pv1–2, and mv with thickened, bulbous base. Leg III with setation generally similar to female but with tarsal setae av1–2 and pv1–2 modified as on leg II. Leg IV strongly modified; femur enlarged, with ventral apophysis bearing partially fused, spurlike ventral seta, dorsal setae thickened and spinelike, especially ad1; genu with ventral seta with bulbous base; tibia with ventral setae av and pv likewise modified; tarsus with seta mv with bulbous base, setae av1 and av2 somewhat longer than pv1 and pv2. Pretarsi relatively short.

MATERIAL EXAMINED.—All specimens from host plants were collected from the flowers of *Centropogon cornutus* (L.) Druce (Lobeliaceae) from the following Trinidad localities: Andrews Trace, 10 mi N Arima, 24 February 1979, R. K. Colwell (#T232) (3 females); same locality, 21 February 1976, R. K. Colwell (#U57) (1 female, 1 male); Blanchicheusse Road, mile 18, 21 February 1976, R. K. Colwell (#U56) (1 female); Blanchicheusse Road, Bridge C2/7, 22 August 1980, D. S. Dobkin (#6, 7, 8) (numerous specimens); Arima Valley, Temple Village, 11 August 1975, R. K. Colwell (#T69) (2 females); Carapo Road, 220 meters E Musica Road, 22 February 1979, R. K. Colwell and D. S. Dobkin (#T234) (5 males); Heights of Guanapo Road,

29 December 1973, R. K. Colwell (#T62) (2 females).

Specimens collected from hummingbirds include the following phoretic hosts: ex *Amazilia chionopectus chionopectus* (Gould), La Laja Trace, 10 August 1975, R. K. Colwell (#T30) (1 female); ex *Glaucis hirsuta insularum* Hellmayr and Seilern, Arima Valley, Simla, 22–30 July 1975, R. K. Colwell (#T21, T46, T49, T50, T51, T52, T53) (27 females); same locality, 18 February 1976, R. K. Colwell (#U22, U34) (10 females, 1 male); Andrews Trace, 30 December 1973, R. K. Colwell (#T29) (7 females); Laja Trace, 8–10 August 1975, R. K. Colwell (#T31, T32, T45) (11 females, 2 males).

**SPECIMEN DEPOSITION.**—Figured voucher specimens deposited in UMMZ, other specimens in NMNH, BYU, CNC, IRSNB.

**COMMENTS.**—Our specimens agree well with the species as redescribed by Fain et al. (1977b). However, our interpretation of the posterior lateral chaetotaxy of the male dorsum differs from that presented by the previous authors who had only a single male available for examination. We regard the setae identified by Fain et al. (1977b, Fig. 88) as S1, S2, S3, and S4 as actually r6, S1, S2, and S3, respectively. As the lengths of these setae were used as diagnostic characters in their key ("Setae S3 and S4 much heavier and longer . . . than S2 and S1" [p. 121]), it should be noted that setae S4 are actually very short and S2 are long.

Within the *kirmsei*-group, *P. glaucis* shares the loss of the female metasternal platelets and enlargement of male setae r6, S2, and S3 with *P. hunteri* and *P. mermillion*, conditions we regard as derived. The species retains dorsal setae z3 in both sexes, most marginal setae on the dorsal shield in the female, and relatively short posterior marginal setae in the male, ancestral states which are modified in *P. hunteri* and *P. mermillion*. *P. glaucis* also differs in retaining a completely ornamented male dorsum, an ancestral state in the genus.

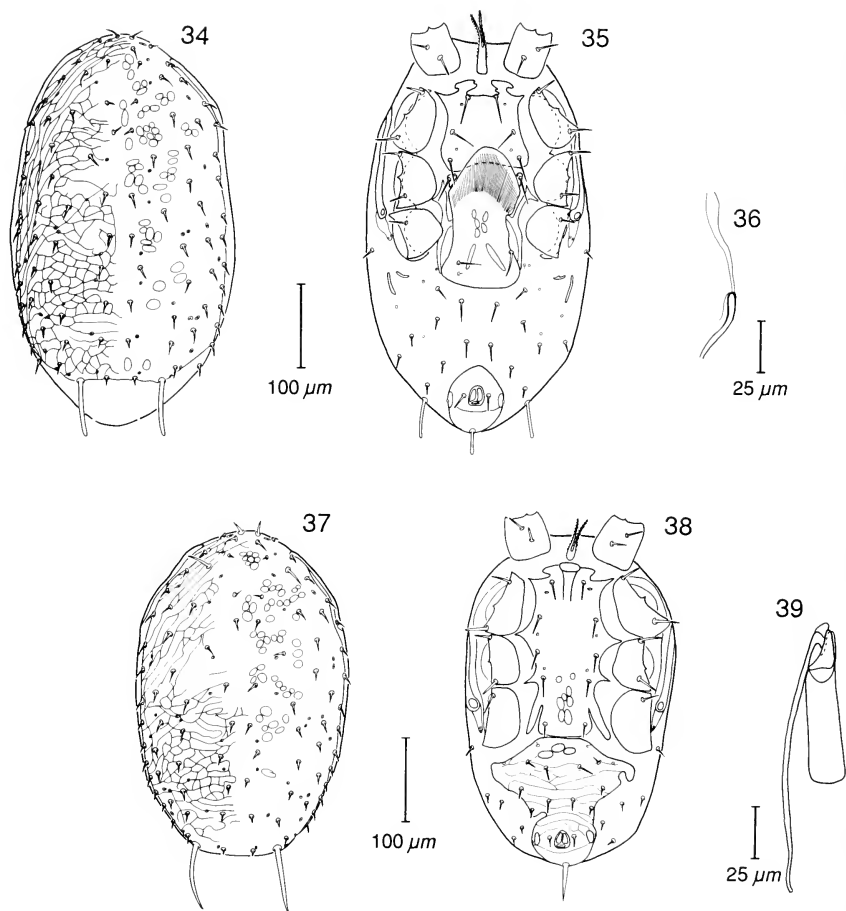
*Proctolaelaps rabulatus*, new species

*Proctolaelaps rabulatus* Colwell, 1986a: 408, nomen nudum

**FEMALE** (Figs. 34–36).—Idiosomal length 486, 480 (456–527), width 287, 301 (257–333)  $\mu\text{m}$ ; dorsal shield length 427, 434 (410–456), width 281, 266 (246–287)  $\mu\text{m}$  ( $n = 10$ ). Dorsal

shield (Fig. 34) with reticulate pattern over entire surface, more weakly developed anteromedially. Dorsal shield with 43 pairs of smooth, simple setae; anterior seta z3 absent; marginal setae r2–6 and R1–6 on edge of shield, R7 on membrane posterior to shield; only 2 pairs of submarginal setae (UR) on lateral membrane posterior of coxae IV. Dorsal setae relatively short and setiform, lengths very uniform between 14–17  $\mu\text{m}$  except as follows: z1, s1–2, and J5 shorter, 7–9  $\mu\text{m}$ ; j2 and z2 slightly longer, 20–22  $\mu\text{m}$ ; Z5 a large spine, 75  $\mu\text{m}$ , seta appearing slightly clubbed in some specimens. Seta j2 unilaterally absent on holotype. Glands, proprioceptors, and muscle scars positioned as indicated in Figure 28.

Venter (Fig. 35) with tritosternum with elongate base and slender, tapering, pilose lacinae. Sternal shield about as long as wide, anterior border deeply incised medially to level of anterior sternal setae; posterior border slightly concave; shield with 3 pairs of setae and 2 pairs of pores; shield smooth, without linear ornamentation. Fourth pair of sternal setae and 3rd pair of sternal pores on metasternal platelets. Genital shield smooth, without linear ornamentation; genital setae on edges of shield (unilaterally anomalous in holotype, with both genital and paragenital seta well on shield); shield distinctly widened behind genital setae. One pair of very short paragenital setae present lateral to genital shield posterior to level of genital setae. Without small sclerites posterior to genital shield. Endopodal apodemes distinct between epigynial shield and coxae III–IV; exopodal sclerites extending from between coxae I–II to behind coxae IV. Two pairs of metapodal plates, external plate very long and thin and much larger than transverse internal plate. Anal shield distinctly longer than wide, ornamentation very weak behind anus, postanal seta spinelike, appearing slightly clubbed in some specimens, about twice as long as paraanal setae. Posterior ventral region with 8 pairs of short setae (JV1–5, Zv1–3), Jv1 and Jv2 typically longer than other anterior setae, Jv5 stout and slightly clubbed in some specimens, 48  $\mu\text{m}$  long; posterior submarginal setae (UR) also typically visible ventrally (Fig. 35). Peritreme extending anteriorly to a point approximating base of dorsal seta s1. Spermathecal system (Fig. 36)



Figs. 34–39. *Proctolaclaps rabulatus*: 34, female dorsum; 35, female venter; 36, female spermathecal system; 37, male dorsum; 38, male venter; 39, male chelicera.

consisting of a very membranous adductor canal approximately 100 μm long; an elongate maturation pouch 33 μm long, which is undivided; and a large, membranous process which is difficult to observe.

Gnathosoma with tectum steeply triangular, without teeth. Chelicerae visible only in dorsoventral view, with fixed digit bidentate and bearing a large, membranous process with two distal teeth; movable digit with at least one tooth. Deutosternum with 7 trans-

verse rows of denticles; rows of denticles wider than in other species and not connected by longitudinal grooves laterally. Rostral setae simple, slender, with internal posterior rostral setae slightly less than twice as long as external posterior rostral setae; capitular setae slender, simple. Corniculi parallel; internal malae not observed. Palps similar to other *Proctolaclaps* species.

Legs I–IV (excluding pretarsi) 85, 71, 70, and 93% of dorsal shield length. Coxae



without linear ornamentation or convex bosses. Setation of genua of legs I, II, III, and IV, respectively, 13-11-9-9, that of tibia: 13-10-8-10 (a2 absent unilaterally from genu III in holotype); all leg setae setiform to filiform except the following spinelike setae: ad1 and pd2 of femur I, ad1 and pd2 of femur II, ad1 of femur III, ad1 and ad2 of femur IV; seta v of femur IV not enlarged.

MALE (Figs. 37-39).—Idiosomal length 410 (392-433), width 253 (240-275) ( $n = 4$ ). Reticulate pattern present covering dorsal shield except in median area on anterior half of shield (Fig. 37). Shield with 43 pairs of setae (z3 absent); most marginal setae normally on shield except R7 on membrane posteroventral to shield. Two pairs of submarginals (UR1) laterad of coxae IV. Dorsal setation essentially similar to female, without enlarged setae (except z2 distinctly longer than others as in female, and spinelike Z5). Glands, proprioceptors, and muscle scars as shown in Figure 37.

Venter (Fig. 38) with tritosternum base distinctly shorter than in female. Sternogenital shield without linear ornamentation, with 5 pairs of setae and 3 pairs of pores. Ventrianal shield widened anteriorly, incorporating metapodal plates, reticulated over entire surface, with 5 pairs of ventral setae on shield, Jv1-3, Zv1-2, in addition to paraanal setae; very short paragenital setae present on anterior edge of shield. Three pairs of ventral setae (Jv4, Jv5, and Zv3) on membrane. All ventral setae short and setiform (including Jv5), Jv1 longest (15  $\mu$ m), others 7-10  $\mu$ m. Paraanal setae approximately one-third as long as very thick, blunt postanal seta (44  $\mu$ m). Peritremes similar to female, extending anteriorly in the vicinity of seta s1. Endopodal apodemes fused to sternogenital shield; exopodal sclerites well developed laterad of coxae.

Gnathosoma with tectum triangular as in female, without teeth. Chelicerae visible only in dorsoventral view, dentition not observable; with long, straight spermatodactyl projecting posteroventrally, 130  $\mu$ m long (Fig. 39). Corniculi shorter and stouter than in female, widely spread basally; other features of gnathosoma as on female.

Legs I-IV (excluding pretarsi) 84, 70, 70, and 93% of dorsal shield length. Coxae without linear ornamentation or convex bosses. Leg I generally similar to female except some

setae of femur slightly more spinelike. Leg II distinctly thickened, setae ad1, pd2, and all three ventral setae in the form of thick spines; genu and tibia each with seta pv a thick spine; tarsus with setae av1-2, pv1-2, and mv with thickened, bulbous base, although less modified than in other members of the *kirmsei*-group. Leg III with setation generally similar to female but with tarsal setae av1-2, and pv1-2 modified as on leg II. Leg IV strongly modified; femur enlarged, with ventral apophysis bearing partially fused, spurlike ventral seta, seta uniquely modified, having a very obvious tooth about midway along seta; dorsal femoral setae thickened and spinelike, especially ad1; genu with ventral seta with bulbous base; tibia with ventral setae av and pv likewise modified; tarsal setae generally unmodified. Pretarsi relatively short.

ETYMOLOGY.—The specific name *rabulatus* is from the Latin meaning "brawling."

MATERIAL EXAMINED.—All specimens were collected from the flowers of *Mandevilla hirsuta* (A. Rich.) K. Schum. (Apocynaceae) from the following Trinidad localities: Arima Valley, Temple Village, Cricket Pitch, 17 February 1979, R. K. Colwell (#T225) (holotype and 1 paratype female, 2 paratype males); Waller Field, 25 August 1980, D. S. Dobkin (#65) (5 females, 2 males); same data (#66) (3 females). No specimens are yet known from hummingbird phoretic hosts.

SPECIMEN DEPOSITION.—Holotype female and figured paratype male deposited in UMMZ, other paratypes in NMNH, BYU, CNC.

COMMENTS.—This species shares certain characteristics with *P. mexicanus*, notably the widened deutosternal denticle rows, and the tendency for the large, posterior setae to become clubbed. This latter condition is much more obvious in immatures of *P. rabulatus* than in the adults. These species retain certain ancestral character states suggesting that they may be the sister-group of a clade containing the remaining species in the group. These include the lack of modification of the male dorsal setation and the widened ventrianal shield of the male (more so in *P. rabulatus* than in *P. mexicanus*). *P. rabulatus* may be readily distinguished from *P. mexicanus* by possession of derived states including: in both sexes presence of paragenital setae and absence of dorsal seta z3, and in the male by

the short form of seta Jv5 and the toothed ventral seta of femur IV. *P. rabulatus* retains the ancestral states of most marginal setae on the dorsal shield and metasternal platelets present in the female.

#### The *Proctolaelaps belemensis* group.

We group the remaining New World flower-inhabiting *Proctolaelaps* as the "*belemensis*-group." Fain et al. (1977a, 1977b) described *P. belemensis* from numerous species of hummingbirds from Brazil, Panama, Venezuela, and Trinidad. They noted that this species "differs markedly" (p. 133) from the other flower-associated *Proctolaelaps* and listed a set of character states that we regard as a combination of ancestral and derived conditions. Two additional taxa, *P. cyanocompsae* (new status) and *P. spiralis*, share the derived character states that diagnose this group. These species share the hypothetically apomorphic character states of enlargement of dorsal setae j1 in both sexes and the strongly tapered epigynial plate in the female. These species are otherwise rather more plesiomorphic than species in the *kirmsei*-group. Both sexes retain expanded posterior rows of deutosternal teeth and more strongly developed ornamentation on the ventral sclerites. Also males have a broad ventrianal sclerite and simple setae on the legs, and the enlarged seta v of femur IV retains a movable articulation and is not borne on a cuticular tubercle.

During our initial work in Trinidad, we identified mites exhibiting these characteristics from many host plants as *P. belemensis* (e.g., Colwell 1979). Closer examination of morphology, behavior, and host associations allowed us to distinguish four distinct forms that differ primarily in body size, lengths of posterior and marginal setae, and male spermatodactyl morphology. Because these forms exhibit distinct host plant preferences, and no morphological intermediates were discovered, we regard them as separate species. Similarly, because two of these new species are more similar to the previously named "subspecies" *cyanocompsae* than to the nominate subspecies, we give full specific status to the former. Because the morphological differences among these species are relatively minor compared with species in the *kirmsei*-group, a cautionary note is in order. Downes (1990) demonstrated that development in dif-

ferent freshwater mussel hosts can significantly affect the morphology of unionicolid water mites to the extent that offspring of a single female raised on different hosts can exhibit adult morphologies of more than one previously recognized "species." Such host effects could certainly account for character differences such as body size exhibited by the *belemensis*-group species described below. On the other hand, these species are also easily distinguished by male spermatodactyl morphology, a genitalic character that is perhaps less prone to influence by host plant morphology (Eberhard 1985). Experimental transfers of juvenile flower mites to other host plants or study of characters not influenced by host plant morphology or chemistry such as allozymes or nucleic acid sequences will provide the test for the hypothesis that our collections represent distinct species.

The four species of the *belemensis*-group collected in Trinidad are very similar. So, in order to conserve space, a full description is given only for *P. belemensis*. The new species are diagnosed with reference to that species, *P. cyanocompsae*, and each other.

Specimens referable to the *belemensis*-group were collected in the Arima Valley and at Waller Field, Trinidad, from 4 species of hummingbirds (1973–1976): *Chlorestes notatus notatus* (C. Reichenbach) (1 female on 1 bird), *Glaucis hirsuta insularum* Hellmayr and Seilern (60 females and 9 males on 25 birds), *Phaethornis guy guy* (Lesson) (13 females and 1 male on 5 birds), *Phaethornis longuemareus longuemareus* (Lesson) (5 females on 2 birds). These specimens will not be listed separately after the species accounts because they had not yet been identified to the species level at the time of this writing.

*Proctolaelaps belemensis* Fain, Hyland and Aitken, 1977

*Proctolaelaps belemensis* Fain, Hyland and Aitken, 1977a: 185

*Proctolaelaps belemensis* Fain, Hyland and Aitken, 1977b: 133

*Proctolaelaps belemensis* Hyland, Fain and Moorhouse, 1978: 263

*Proctolaelaps belemensis* Colwell, 1986a: 408

NOT *Proctolaelaps belemensis* Colwell, 1979: 463

This species was briefly diagnosed from female and male specimens collected from the nares of *Threnetes leucurus* from Belem, Brazil (Fain et al. 1977a). A more complete description, figures of both sexes, and new host and locality records were given later

(Fain et al. 1977b). The latter authors listed *Campylopterus largipennis*, *Phaethornis superciliosus*, and *Glaucis hirsuta* as additional hummingbird hosts and recorded the species from additional localities in Brazil, Panama, Venezuela, and two localities in Trinidad: Cumuto and Ravine Sable Trace, Vega de Oropouche. Hyland et al. (1978) recorded the species from Mexico from *P. superciliosus* and *Campylopterus hemileucurus*. In the published descriptions, measurements were given only for the holotype female and one male specimen. Because only a single male and female attributable to this species were collected during our studies, we include in the following redescription some data taken from two female paratypes and one female from the Mexican collection reported by Hyland et al. (1978).

**FEMALE** (Figs. 40–44).—Idiosomal length of Trinidad specimen 591, in other specimens examined length range (573–620)  $\mu\text{m}$ , width 468 (421–439); dorsal shield length 521 (538–565), width 380 (392–404)  $\mu\text{m}$ . Dorsal shield (Fig. 40) with transverse, linear pattern over entire surface, reticulations largely confined to posterior edge and median area. Dorsal shield with 44 pairs of smooth, simple setae; marginal setae r2–6 and R1–6 on edge of shield, R7 on membrane posterior to shield; 3 pairs of submarginal setae (UR) on lateral membrane posteriad of coxae IV. The following measurements of dorsal setae were taken from the figured Trinidadian specimen: j1 a stout spine, 44  $\mu\text{m}$  long; j2, z1, s1, and J5 shorter than other dorsal setae, about 13–15  $\mu\text{m}$  (J5 unilaterally absent); most other dorsal setae subequal, 20–24  $\mu\text{m}$ , Z5 a stout spine, 88  $\mu\text{m}$ ; most marginal setae similar in length to dorsal setae, r3 and R7 longer than others, both 33  $\mu\text{m}$ . Glands, proprioceptors, and muscle scars positioned as indicated in Figure 40.

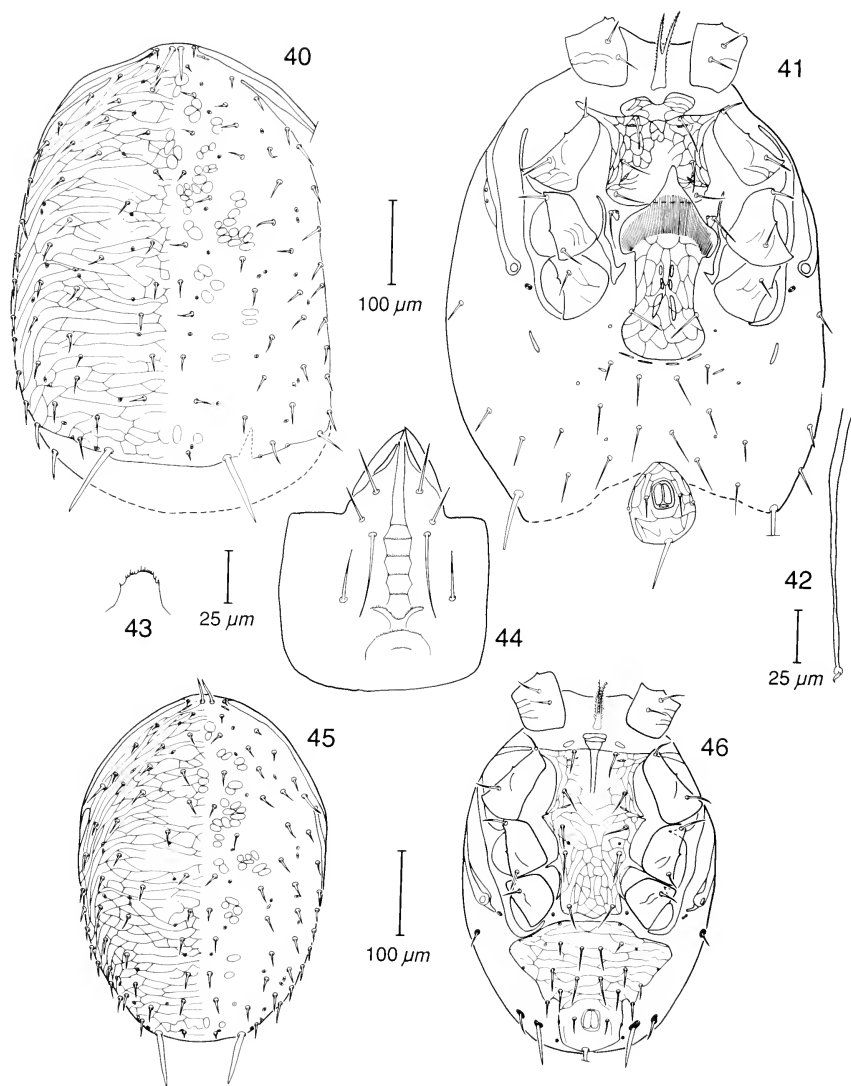
Venter (Fig. 41) with tritosternum with elongate base and slender, tapering, pilose laciniae. Sternal shield longer than wide, posterior border generally straight, with 3 pairs of setae and 2 pairs of pores; anterior lobes of shield very weakly sclerotized, but with distinct linear pattern; reticulate pattern also present over most of shield except central and posterior areas. Fourth pair of sternal setae and 3rd pair of sternal pores on metasternal platelets. Genital shield with reticulate orna-

mentation, shield distinctly widened behind genital setae. With 6 small transverse sclerites posterior to genital shield. Endopodal apodemes distinct between epigynial shield and coxae III–IV; exopodal sclerites extending from middle of coxae II to behind coxae IV. One pair of elongate metapodal plates. Anal shield longer than wide, reticulate ornamentation covering most of shield; postanal seta spinelike, at least twice as long as paraanal setae. Posterior ventral region with 7 pairs of filiform setae (JV1–4, Zv1–3), Jv5 a stout spine; lengths of Jv1–5, 40, 46, 44, 37, 75  $\mu\text{m}$ , Zv1–3, 22, 44, 26  $\mu\text{m}$ . Posterior submarginal setae (UR) also typically visible ventrally (Fig. 41). Peritreme extending anteriorly to a point approximating base of dorsal seta z1. Spermathecal system (Fig. 42) simple, consisting of an adductor canal wider nearer to external opening, approximately 132  $\mu\text{m}$  long; a very short, bulbous maturation pouch at inner terminus of canal; and a very short, hooked spermiduct.

Gnathosoma with tectum rounded and strongly toothed (Fig. 43). Chelicerae visible only in dorsoventral view, with fixed digit bearing a row of small teeth along the length of the digit and a large, membranous antiaxial process with two distal teeth; movable digit not clearly observed. Subcapitulum (Fig. 44) with deutosternum having 7 rows of denticles; anterior 6 rows connected; 5th and 6th rows widened. Rostral setae simple, slender, with internal posterior rostral setae more than twice as long as external posterior rostral setae; capitular setae slender, simple. Corniculi convergent; internal malae not observed. Palps similar to other *Proctolaelaps* species.

Legs I–IV (excluding pretarsi) 110, 87, 76, and 109% of dorsal shield length. All coxae with transverse lines ventrally, without bosses. Setation of genua of legs I, II, III, and IV, respectively, 13-11-9-9, that of tibia: 13-10-8-10; all leg setae setiform to filiform, tarsal setae especially long; without spinelike setae.

**MALE** (Figs. 45–46).—Redescription based on single Trinidadian male. Idiosomal length 430  $\mu\text{m}$ , width 316  $\mu\text{m}$ . Reticulate pattern present covering dorsal shield (Fig. 45). Shield with 44 pairs of setae, all marginal setae on shield except R7. One pair of submarginals (UR1) laterad of coxae IV. Relative lengths of dorsal setae as in female; j1-33, r3-29, R7-26,



Figs. 40–46. *Proctolaelaps belemensis*: 40, female dorsum; 41, female venter; 42, female spermathecal system; 43, female tectum; 44, female subcapitulum; 45, male dorsum; 46, male venter.

25–62  $\mu\text{m}$ ; most other dorsal setae 11–15  $\mu\text{m}$ . Glands, proprioceptors and muscle scars as shown in Figure 45.

Venter (Fig. 46) with tritosternum shorter than in female. A pair of small, pre-endopodal sclerites adjacent to genital opening. Sternogenital shield with reticulate pattern well developed over entire shield except anterior-medially, with 5 pairs of setae and 3 pairs of pores. Ventrianal shield widened anteriorly, incorporating metapodal plates, reticulated over entire surface, with 7 pairs of ventral setae on shield, Jv1–4, Zv1–3, in addition to paraanal setae; thickened seta Jv5 on membrane; other setae filiform, relative lengths as in female. The unilateral absence of Zv3 and the position of Jv4 on small extensions of the ventrianal plate are interpreted here as anomalies. Jv4 is off the plate in the "allotype" described for this species, as well as in all other species of the *belemensis*-group. Paraanal setae relatively short, blunt postanal seta broken. Peritremes as in female, extending anteriorly to the vicinity of seta z1. Endopodal apodemes fused to sternogenital shield; exopodal sclerites well developed laterad of coxae.

Gnathosoma with tectum as in female, broadly triangular and toothed. Chelicerae only visible in dorsoventral view. Cheliceral digits similar to female; spermatodactyl essentially straight, projecting posterioventrally, 140  $\mu\text{m}$  long; other features of gnathosoma as on female.

Legs I–IV (excluding pretarsi) 118, 88, 79, and 114% of dorsal shield length. Coxae with linear ornamentation as in female. Legs generally similar to female except some setae shorter and more spinelike; these include av1 of femur I, av1 of femur II, av and pv of genu II, and pv of genu III. Ventral seta of femur IV enlarged, but with movable articulation. Pretarsi all elongate.

MATERIAL EXAMINED.—In addition to two paratypes from the type locality in Brazil kindly provided by Dr. Fain, we have examined one of the Mexican specimens reported by Hyland et al. (1978) and the following specimens from Trinidad: from flowers of *Monotagma spicatum* (Aubl.) Macbr. (Marantaceae), La Laja Trace, 8 mi N Arima, 17 February 1976, R. K. Colwell (#U64) (figured female and male).

SPECIMEN DEPOSITION.—Figured voucher specimens deposited in UMMZ.

COMMENTS.—Our specimens generally agree with the published description and figures. The presence of setae Jv4 on the ventrianal shield of the male is regarded as an anomaly in our specimen. This species is one of two relatively small species in the group. Differences between this species and the other small species, *P. contumex*, are discussed below.

We believe it is unlikely that *Monotagma spicatum* is the true host plant of *P. belemensis* for two reasons. First, although more than a hundred flowers of this plant were examined, only two specimens of *P. belemensis* were found. Second, the phoretic hosts from which *P. belemensis* has been collected elsewhere (*Glaucis hirsuta*, *Threnetes leucurus*, *Phacothornis superciliosus*, *Campylopterus largipennis*, and *C. hemileucurus* [Fain et al. 1977a, 1977b, Hyland et al. 1978]) all have long bills (3.2, 3.2, 3.8, 3.8, and 3.3 cm, respectively), whereas the flowers of *Monotagma spicatum* are less than 2 cm in length. In general, hummingbirds feed on flowers that approximate their bill length (Feinsinger and Colwell 1978). The true host plant (or plants) of *P. belemensis* thus, almost surely, has flowers more than 3 cm in length.

*Proctolaelaps contumex*, new species

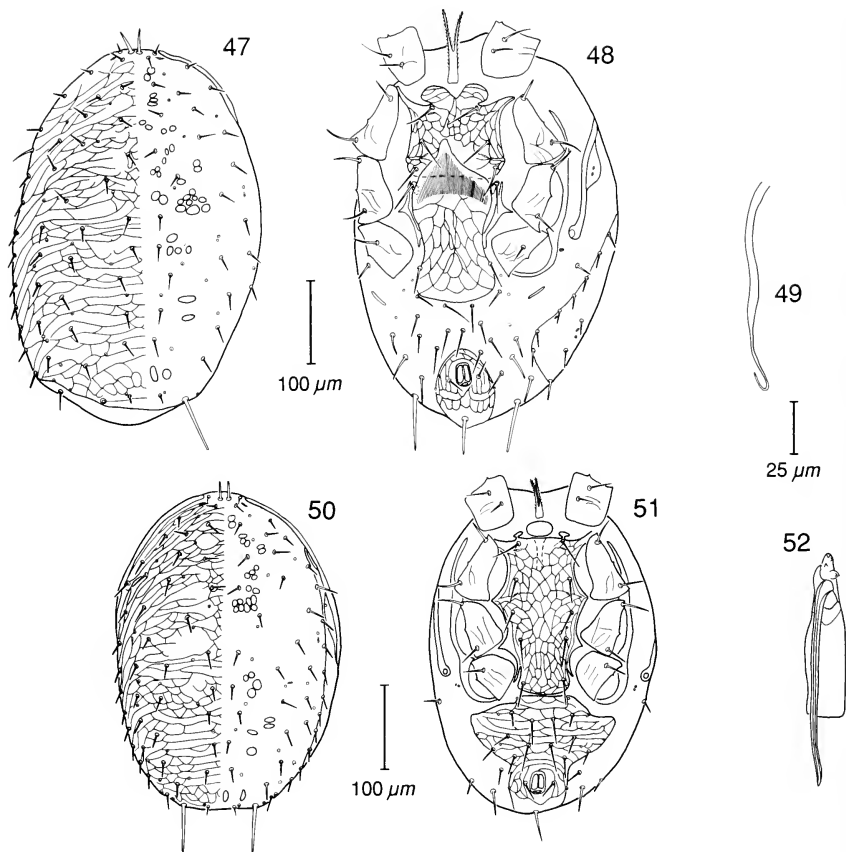
*Proctolaelaps belemensis* Colwell, 1979: 463, NOT *P. belemensis* Fain, Hyland and Aitken, 1977

*Proctolaelaps contumex* Colwell, 1986a: 408, nomen nudum

DIAGNOSIS.—This species is very similar to *P. belemensis*. Females (Figs. 47–49) differ primarily in the distinctly smaller body size (idiosomal length of holotype and paratype, 468–538  $\mu\text{m}$ , width 328–363  $\mu\text{m}$ ; dorsal shield length 450–456, width 322–328  $\mu\text{m}$ ), and the form of the spermathecal system, which consists of a long, simple tube that is thickened towards the exterior and tapers to a fine point, entire tube 123  $\mu\text{m}$  long (Fig. 49). Body setae proportioned as in *P. belemensis*, but setae absolutely shorter.

MALE (Figs. 50–52).—Similar to *P. belemensis* but smaller, both specimens with idiosomal length 410  $\mu\text{m}$ , width 254–281  $\mu\text{m}$ . Spermatodactyl (Fig. 52) much shorter than in *P. belemensis*, length 100–105  $\mu\text{m}$ . Most body setae proportioned as in *P. belemensis*, but setae absolutely shorter; posterior ventral seta Jv5 only slightly enlarged, 33  $\mu\text{m}$  long.

ETYMOLOGY.—The specific name *contumex* is modified from the Latin *contumax*, meaning "defiant" and is an adjective.



Figs. 47–52. *Proctolaelaps contumex*: 47, female dorsum; 48, female venter; 49, female spermathecal system; 50, male dorsum; 51, male venter; 52, male chelicera.

**MATERIAL EXAMINED.**—All specimens were collected from flowers of *Cephaelis muscosa* Sw. (Rubiaceae) as follows: Blanchisseuse Road, mile 19, 13 March 1979, R. K. Colwell (#T275) (holotype and one other female, 1 male, 1 larva); Arima Valley, Temple Village, Cricket Pitch, 16 February 1979, R. K. Colwell (#T201) (1 male).

**SPECIMEN DEPOSITION.**—Holotype female and 1 paratype male in UMMZ, other paratypes in BYU.

*Proctolaelaps certator*, new species

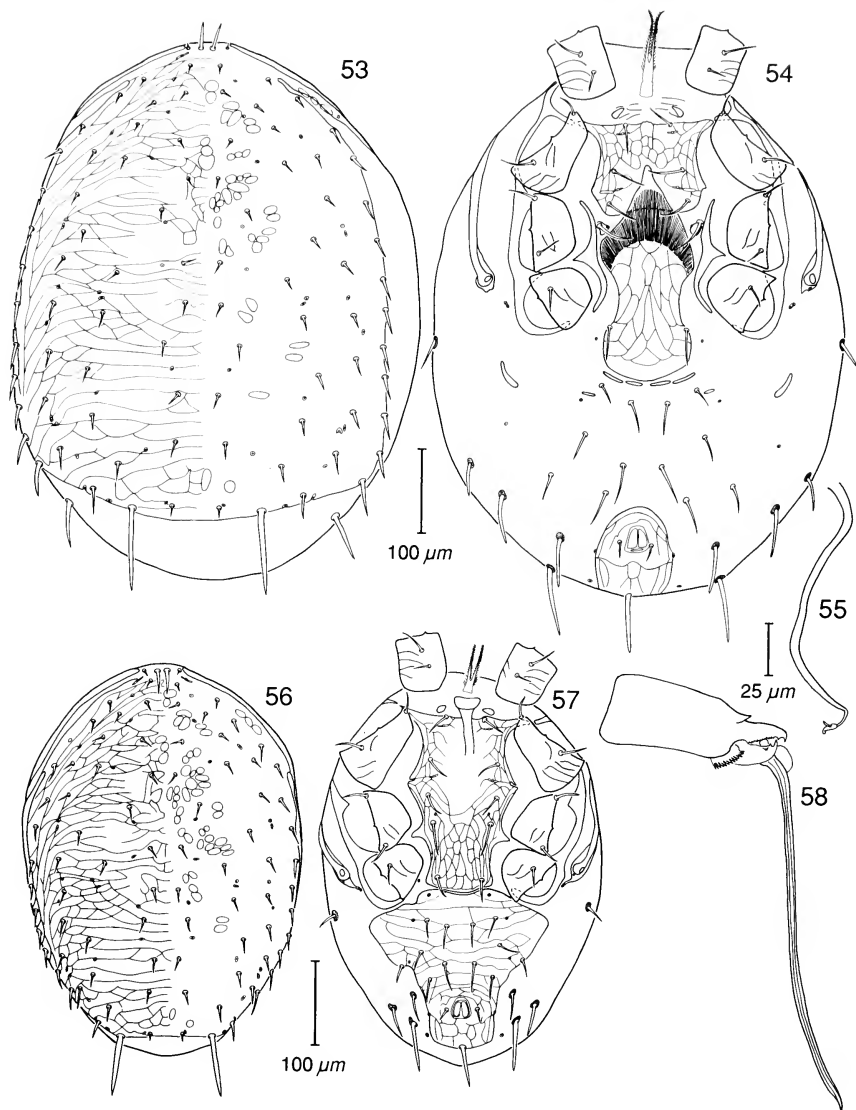
*Proctolaelaps certator* Dobkin, 1985: 536, nomen nudum

*Proctolaelaps certator* Colwell, 1986a: 408, nomen nudum

*Proctolaelaps certator* Colwell, 1986b: 491, nomen nudum

*Proctolaelaps certator* Heyneman et al., 1990: 468, nomen nudum

**FEMALE** (Figs. 53–55).—Idiosomal length 620, 659 (556–702), width 468, 496 (445–527)  $\mu\text{m}$ ; dorsal shield length 573, 562 (544–585), width 450, 430 (404–450)  $\mu\text{m}$  ( $n = 10$ ). Dorsal shield (Fig. 53) with transverse, linear pattern over entire surface, reticulations largely confined to median area. Dorsal shield with 44 pairs of smooth, simple setae; marginal



Figs. 53–58. *Proctolaelaps certator*: 53, female dorsum; 54, female venter; 55, female spermathecal system; 56, male dorsum; 57, male venter; 58, male chelicera.

setae r2-6 and R1-6 on edge of shield, R7 on membrane posterior to shield; 3 pairs of submarginal setae (UR) on lateral membrane posterior of coxae IV. The following measurements of dorsal setae were taken from the holotype: j1 a stout spine, 33  $\mu\text{m}$  long; j2, z1, s1, and J5 shorter than other dorsal setae, about 8-11  $\mu\text{m}$ ; most other dorsal setae subequal, 13-15  $\mu\text{m}$ , Z5 a stout spine, 106  $\mu\text{m}$ ; marginal setae longer than most dorsal setae, gradually increasing in length from anterior to posterior, r3 (24  $\mu\text{m}$ ) only slightly longer than r2 (22  $\mu\text{m}$ ); R7 longer than others (59  $\mu\text{m}$ ). Glands, proprioceptors, and muscle scars positioned as indicated in Figure 53.

Venter (Fig. 54) very similar to *P. belemensis* except region of sternal shield anterior to first sternal setae lineate and with a pair of distinct pre-endopodal sclerites; genital shield more elongate and tapering anteriorly. Posterior ventral setae Jv4 and Jv5 elongate and spinelike, 63 and 88  $\mu\text{m}$  long. Spermathecal system (Fig. 55) simple, consisting of an adductor canal wider nearer to external opening, approximately 145  $\mu\text{m}$  long; a very short, bulbous maturation pouch at inner terminus of canal; and a very short, hooked spermiduct. Gnathosoma and legs as in *P. belemensis*.

MALE (Figs. 56-58).—Idiosomal length 500 (486-509), width 320 (313-351)  $\mu\text{m}$  ( $n = 10$ ). Linear-reticulate pattern covering dorsal shield (Fig. 56). Shield with 44 pairs of setae, all marginal setae on shield except R7. One pair of submarginals (UR1) laterad of coxae IV. Relative lengths of dorsal setae as in female; j1-35, r3-29, R7-41, Z5-78  $\mu\text{m}$ ; most other dorsal setae 13-18  $\mu\text{m}$ . Glands, proprioceptors, and muscle scars as shown in Figure 56.

Venter (Fig. 57) with tritosternum shorter than in female. A pair of small presternal sclerites adjacent to genital opening. Sternogenital shield with reticulate pattern well developed over entire shield except anteromedially, with 5 pairs of setae and 3 pairs of pores. Ventrianal shield widened anteriorly, incorporating metapodal plates, reticulated over entire surface, with 6 pairs of ventral setae on shield, Jv1-3, Zv1-3, in addition to paraanal setae; setae Jv4-5 on membrane; Jv5 a thickened spine, 64  $\mu\text{m}$  long; other setae filiform, relative lengths as in female. Paraanal setae relatively short (22  $\mu\text{m}$ ), postanal seta a thickened spine 51  $\mu\text{m}$  long.

Peritremes as in female, extending anterior to the vicinity of seta z1. Endopodal apodemes fused to sternogenital shield; exopodal sclerites well developed laterad of coxae.

Gnathosoma with tectum as in female, broadly triangular and strongly toothed. Chelicerae with fixed digit with a large, subapical tooth and a row of fine teeth, membranous, bidentate process on paraxial surface; movable digit strongly hooked, with a subapical tooth. Arthrodial membrane at base of movable digit strongly fimbriate. Spermatodactyl slightly curving distally, projecting posteriorly, 180-185  $\mu\text{m}$  long; other features of gnathosoma as on female.

Legs I-IV (excluding pretarsi) 108, 81, 82, and 106% of dorsal shield length. Coxae with linear ornamentation as in female. Legs generally similar to female except some setae shorter and more spinelike; these include av1 of femur I, av1 of femur II, av and pv of genu II, and pv of genu III. Ventral seta of femur IV enlarged, but with movable articulation. Pretarsi all elongate.

ETYMOLOGY.—The specific name *certator* is from the Latin meaning "disputant" and is a masculine noun in apposition.

MATERIAL EXAMINED.—Holotype female from flowers of *Heliconia bihai* L. (Musaceae), Andrews Trace, 10 mi N Arima, 21 February 1976, R. K. Colwell (#U60) (holotype and 3 paratype females); the following collections also from *H. bihai* (all paratypes): Simla Research Station, 4 mi N Arima, 15 February 1976, R. K. Colwell (#U59) (1 female, figured and 1 other male); same locality, March 1980, D. S. Dobkin (#9) (4 females); same data (#18) (2 females); same data (#26) (2 females, 6 males); same data (#28) (3 females, 2 males); same data (#45) (2 females, 3 males); Waller Field, 22 February 1976, R. K. Colwell (#U63) (1 female, 1 male).

The following collections from flowers of *Heliconia tortuosa* Griggs (Musaceae): Temple Village, Davis Home Road, 11 March, 1980; D. S. Dobkin (#T533) (2 females, 2 males); Simla Research Station, March 1980, D. S. Dobkin (#53) (1 female).

The following specimens from flowers of *Aechmea fendleri* Andre (Bromeliaceae): top of Arima Valley, Textel Road, 1 March 1979, R. K. Colwell (#T252) (3 females).

The following specimens from flowers of *Costus scaber* Ruiz & Pavón (Zingiberaceae):



Andrews Trace, 10 mi N Arima, 1 August 1975, R. K. Colwell (#T7) (4 females); La Laja Trace, 8 mi N Arima, 23 February 1976, R. K. Colwell (#U33) (2 females, 1 male); near Simla Research Station, 4 mi N Arima, 11 June 1976, P. Feinsinger (#W16) (6 females); same locality, 12 August 1975, R. K. Colwell (#T59) (2 females).

**SPECIMEN DEPOSITION.**—Holotype and paratypes in UMMZ, other paratypes in BYU, NMNH, CNC, IRSNB.

**COMMENTS.**—One of four relatively large species in the *belemensis*-group, this species is very similar if not identical to *P. cyano-compae*. The latter species was only diagnosed with reference to *P. belemensis*; the character states listed as diagnostic also occur in *P. certator* and *P. contentiosus* (see below). The only measurements given for *P. cyano-compae* were idiosomal length and width, and these values fall within the range of *P. certator* as described above. We were unable to examine the holotype of *P. cyano-compae*, and until this specimen or additional material from the type-locality can be described in better detail, or males are discovered, the relationship between *P. cyano-compae* and *P. certator* cannot be resolved with certainty.

*Proctolaelaps contentiosus*, new species

*Proctolaelaps contentiosus* Colwell, 1986: 408, nomen nudum

*Proctolaelaps contentiosus* Heyneman et al., 1990: 467, nomen nudum.

**DIAGNOSIS.**—This species is very similar to *P. certator*. Females (Figs. 59–61) differ primarily in the distinctly larger body size (idiosomal length 702, 726, [684–784], width 486, 516 [468–626]  $\mu\text{m}$ ; dorsal shield length 626, 621 [585–644], width 468, 469 [427–486]  $\mu\text{m}$  [ $n = 10$ ]), the greater length of anterior marginal seta  $r_3$  compared with other anterior marginal setae ( $r_3$  1.25–1.5 times the length of  $r_2$  and  $r_4$ ), and the greater length of posterior ventral seta  $Jv_5$  (1.7 times the length of  $Jv_4$ , vs. 1.2–1.4 in *P. certator*).

**MALE** (Figs. 62–64).—Similar to *P. certator* but larger, idiosomal length 534 (527–544), width 361 (331–392)  $\mu\text{m}$  ( $n = 4$ ). Anterior marginal seta  $r_3$  enlarged as in female; posterior ventral region with setae  $Zv_3$  usually absent (unilaterally present in 1 of 4 specimens, absent in all others); posterior ventral seta  $Jv_4$  shorter than  $Jv_2$ . Spermatodactyl

(Fig. 64) distinctly shorter than in *P. certator*, length 160–165  $\mu\text{m}$ .

**ETYMOLOGY.**—The specific name *contentiosus* is from the Latin meaning “given to combat.”

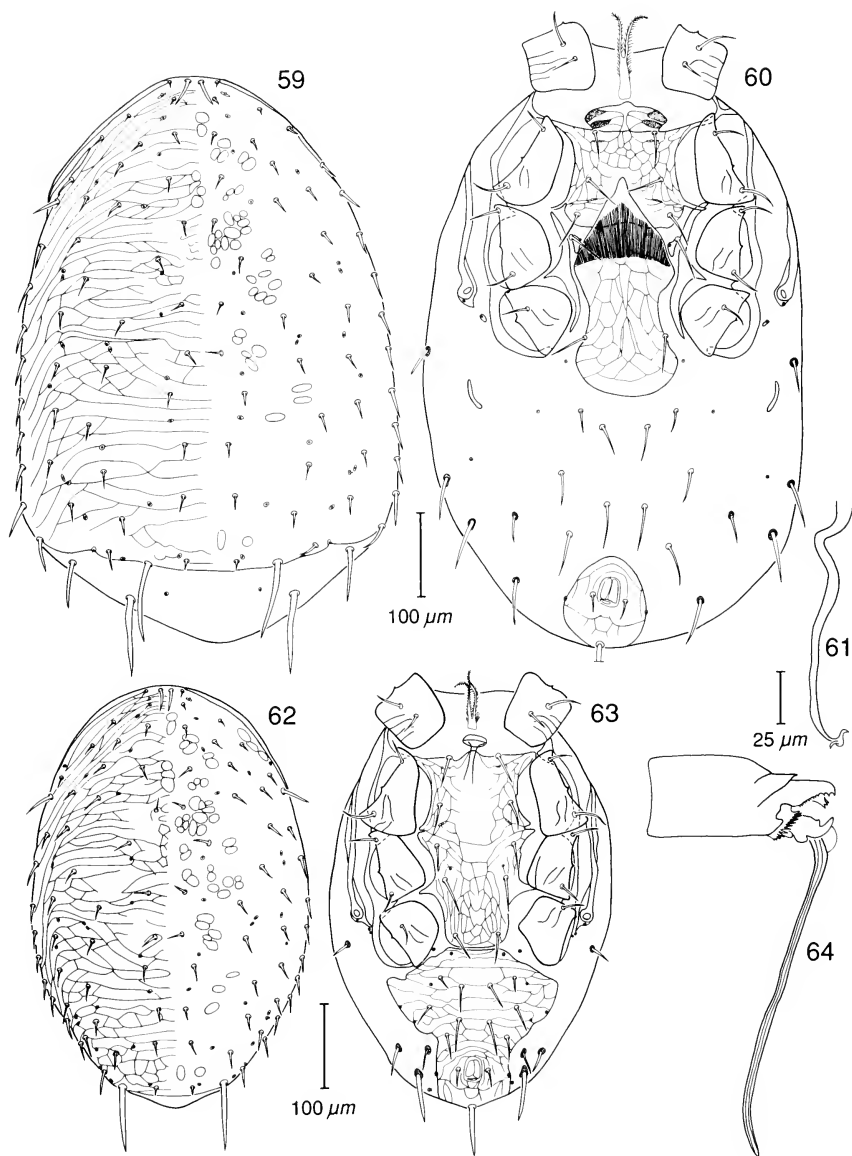
**MATERIAL EXAMINED.**—All specimens were collected from flowers of *Renanthera exaltata* L. f. (Zingiberaceae) as follows: La Laja Trace, 8 mi N Arima, 8 August 1975, R. K. Colwell (#T55) (holotype and one other female, 2 males); same locality, 5 August 1975, R. K. Colwell (#T16) (6 females); same locality, 23 February 1976, R. K. Colwell (#U52) (figured male); La Laja Plantation, 2 March 1979, R. K. Colwell (#T258) (2 females, 2 males).

**SPECIMEN DEPOSITION.**—Holotype and paratypes in UMMZ, other paratypes in BYU, USNM, CNC.

**COMMENTS.**—*Proctolaelaps contentiosus* is the largest species now known in the *belemensis*-group. It may be distinguished from *P. certator* by the different length proportions described above. It is interesting to note that although males are absolutely larger than in *P. certator*, the spermatodactyl length is distinctly shorter in *P. contentiosus*. We have found spermatodactyl length in species of the *belemensis*-group to show little within-species variation, but differences between species are marked.

#### Key to the Species of Flower-inhabiting *Proctolaelaps* in Trinidad

- Both sexes with dorsal setae  $j_1$  stout and spine-like, 2.5–3 times longer than setae  $j_2$ ; female with anterior edge of genital plate strongly tapering; male with spinelike ventral seta of femur IV articulating directly with segment, not on an enlarged process; male leg setae otherwise simple, without expanded, bulbous bases ..... *belemensis*-group 6
- Both sexes with dorsal setae  $j_1$  similar in length to setae  $j_2$ , rarely somewhat enlarged (*P. rabulatus*); female with anterior edge of genital plate broadly rounded; male with spinelike ventral seta of femur IV fused to an enlarged process of the segment; male with some ventral seta of tarsus II, genu and tibia IV with expanded, bulbous bases ..... *kirmsei*-group 2
- Female with anterior lobes of sternal shield narrowly connected to shield; anterior lobes without linear pattern; female with a pair of very small paragenital setae off shield laterad of genital setae; male with ventrianal shield widened anteriorly, without separate metapodal plates; male with all dorsal shield setae (except  $Z_5$ )



Figs. 59–64. *Proctolaelaps contentiosus*: 59, female dorsum; 60, female venter; 61, female spermathecal system; 62, male dorsum; 63, male venter; 64, male chelicera.

- relatively short, not longer than the distances between the setae ..... *rabulatus*
- Female with anterior lobes broadly connected to sternal shield, lobes with linear pattern; female without paragenital setae; male ventrianal shield parallel-sided, metapodal plates large and distinct; male with some dorsal setae enlarged and spinelike, much longer than the distance to the next posterior seta ..... 3
3. Female with metasternal setae on platelets; male with central dorsal setae (j5–6 and J1, z5–6 and Z1, s5–6 and S1) very large and spinelike, and posterior dorsal and marginal setae (except Z5) all very short (S2–3 similar in length to S5) ..... 4
- Female with metasternal setae on membranous cuticle, metasternal platelets absent; male with central dorsal setae variably formed, and with some posterior and/or marginal setae very large and spinelike (S2–3 at least twice as long as S5) ..... 5
4. Both sexes with dorsal seta j2 similar in length to j1; female with maturation pouch of spermathecal system very short, only slightly longer than wide; male with dorsal setae z2, z3, and s3 very short, not longer than distance to next posterior seta ..... *kirmisci*
- Both sexes with dorsal seta j2 approximately twice as long as j1; female with maturation pouch of spermathecal system about 2.5 times longer than wide; male with dorsal setae z2, z3 and s3 enlarged and spinelike, longer than the distance to the next posterior seta ..... *jurgatus*
5. Both sexes with dorsal setae z3 absent; female with all marginal setae except r2–3 off the dorsal shield, posterior submarginal (UR) setae and ventral seta Jv4 long and spinelike, longer than distance to next posterior seta; male with 3 pairs of posterior marginal setae (R1–3) enlarged and spinelike, longer than adjacent setae S1–3, other posterior marginal setae (R4–7) absent ..... *mermillion*
- Both sexes with dorsal setae z3 present; female with all marginal setae except R7 on dorsal shield, posterior submarginal setae and ventral seta Jv4 shorter than distance to next posterior seta; male with at least 5 pairs of posterior marginal setae, all posterior marginals relatively short; posterior setae S2–3 very large and spinelike, at least 5 times longer than adjacent marginal setae R2–3 ..... *glaucis*
6. Female dorsal shield length less than 480  $\mu\text{m}$ ; male spermatodactyl length 100–105  $\mu\text{m}$  ..... *contumex*
- Female dorsal shield length greater than 520  $\mu\text{m}$ ; male spermatodactyl length greater than 130  $\mu\text{m}$  ..... 7
7. Female dorsal shield length 585–644  $\mu\text{m}$ ; male spermatodactyl length 160–165  $\mu\text{m}$  ..... *contentiosus*
- Female dorsal shield length less than 585  $\mu\text{m}$ , male spermatodactyl length greater than 170 or less than 150  $\mu\text{m}$  ..... 8
8. Female with anterior marginal seta r3 distinctly longer than adjacent marginal setae r2 and r4; male spermatodactyl length 180–185  $\mu\text{m}$  ..... *certator*
- Female with anterior marginal seta r3 similar in length to r2 and r4; male spermatodactyl length 140  $\mu\text{m}$  ..... *belemensis*

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## OXYTROPIS DC.—NAMES, BASIONYMS, TYPES, AND SYNONYMS— FLORA NORTH AMERICA PROJECT

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**ABSTRACT.**—All names known to apply to the genus *Oxytropis* de Candolle in North America are listed with place of publication, type information (where known), type specimen repositories, and notations pertinent to understanding the nomenclatural aspects of the genus. Nomenclatural combinations proposed are: *Oxytropis arctica* R. Brown var. *murrayi* (Jurtzev) Welsh and *O. campestris* (L.) de Candolle var. *roaldii* (Ostenfeld) Welsh.

**Key words:** *Oxytropis*, North America, names, types, synonyms.

Preparation of a revisionary summary of the genus *Oxytropis* de Candolle for the Flora North America Project necessitates that nomenclatural changes and type information be presented prior to publication in that project. The following list consists of synonyms, names, nomenclatural types, and new combinations of names involved with this interesting and complex genus as it occurs in North America. Each name involved with the genus is listed with its bibliographical citation, type information, places of deposit of the types, and other pertinent information as necessary.

All names cited in the literature are included. In some few of them the place of deposition of the type is unknown, and the space for that information is left blank. *Oxytropis* consists of some 57 taxa in 22 species in its North American complement. The taxonomic problems are disproportionate with the size of the genus, however. The large number of synonyms reflects the problematic nature of the taxa within the genus. Further complicating the number of names have been the nomenclatural transfers to earlier published genera *Aragallus* Neck. and *Spiesia* Neck. The conservation of *Oxytropis* DC. forestalled ultimate adoption of either of those generic names. Some authors, Tidestrom for example, discerned the close relationship of *Oxytropis* with *Astragalus* L., and he subsequently made wholesale transfers of the names to that genus. While having considerable merit from a phylogenetic standpoint,

the inclusion would have further burdened an already huge genus and overlooked the divergence of the oxytropes from most of the astragalus complexes. In North America only the introduced *O. riparia* and the indigenous *O. deflexa* are caulescent or have caulescent phases. The porrect beak of the keel is diagnostic for the genus, even though some species of *Astragalus* have extended keel apices; none are truly porrect.

Aside from the problem of nomenclatural transfers, which have added to the list of synonyms, the main difficulties are morphological; there are few consistent morphological features to serve as taxonomic criteria. The pods, with some exceptions, are mainly alike, especially in those taxa that are most alike otherwise. The flowers are similar through the genus, the main differences being in size (and that varies greatly within some species) and color (which also varies within a species and often within the infraspecific categories). The taxonomist has had to rely on features of stipules, leaves, inflorescence, pubescence, and calyx or pod inflation to arrive at a treatment that still lacks absolute consistency. Morphological intermediates, resulting from hybridization or from overlap of widely varying characteristics, tend to cloud the picture. Chromosome number is helpful, to an extent, but plants with differing ploidy levels are known within species and some of the varieties; and chromosome number is not always associated with other morphological features.

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Some workers have looked at the genus as if the taxa were clear and distinctive, resulting in the proliferation of specific and infraspecific names. Each new morphological variant was considered worthy of a name by some students of the genus. Adding to the difficulties of interpretation of taxonomic and nomenclatural problems was the circumboreal nature of the genus. In Alaska and other northern regions of North America, some species were clearly allied closely to Siberian or Eurasian taxa. A paucity of critical materials from Siberia for comparison with the American counterparts made interpretation difficult. Specimens from Siberia in American herbaria are still the exception. In the *campestris* and *borealis* complexes the need for such comparisons is critical. Both species were named prior to any of the North American counterparts, and it was not until the critical review of *Oxytropis* by Barneby (1952) that clarification of many of the problems became a possibility, although the equivalence was discerned earlier by Gray (1884) and others. Much additional work and refinement of the infraspecific taxa in the complexes with circumboreal representation is necessary.

The present writer has examined all but a few of the taxa in the field and has spent almost three decades in their pursuit. It is hoped that this summary of names will be helpful. Works of special importance to this paper include those by Barneby (1952), Boivin (1962, 1967), Bunge (1874), Elisens and Packer (1980, 1982), Gray (1884), Jurtsev (1986), Porsild and Cody (1980), Vasilchenko et al. (1948), and Welsh (1967, 1974, 1977, and 1987).

*Aragallus abbreviatus* Greene, Proc. Biol. Soc. Wash. 18: 12. 1905.

Type: Texas, near Dallas, Limestone prairie, Dallas County, J. Reverchon 603, May 1876; holotype NDC!; isotype NY!; dry calcareous soil near Dallas, Texas, Curtis 603, April, May; cotype GH!, NDC!, NY!

= *Oxytropis lambertii* Pursh var. *articulata* (Greene) Barneby

*Aragallus aboriginum* Greene, Proc. Biol. Soc. Wash. 18: 12. 1905.

Type: Oklahoma, Cimarron Valley, Cherokee Outlet, M. N. Carleton 217, June 1891; holotype US!; photo BRY!

= *Oxytropis sericea* Nuttall var. *sericea*

*Aragallus albertinus* Greene, Proc. Biol. Soc. Wash. 18: 15. 1905.

Type: Saskatchewan, Prince Albert, Lat. 53°, J. M. Macoun 12535 and 12540, July 1896; cotypes NDC!

= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Aragallus albiflorus* A. Nelson, Erythra 7: 62. 1899, nom. nov.

Basionym: *Oxytropis lambertii* Pursh var. *ochroleuca* A. Nelson

= *Oxytropis sericea* Nuttall var. *sericea*

var. *condensatus* A. Nelson, Erythra 7: 62. 1899.

Type: Wyoming, Bitter Creek, Red Desert, Sweetwater County, A. Nelson 4773, 16 June 1898; holotype RM!; isotypes NY!, US!

= *Oxytropis sericea* Nuttall var. *sericea*

*Aragallus alpicola* Rydberg, Mem. N. Y. Bot. Gard. 1: 252. 1900.

Type: Montana, Old Hollowtop near Pony [South Boulder Range, Madison County], P. A. Rydberg & E. Bessey 4503, 9 July 1897; holotype NY!; isotypes GH!, NDC!, US!, NY!

= *Oxytropis campestris* (L.) de Candolle var. *cusickii* (Greenman) Barneby

*Aragallus angustatus* Rydberg, Bull. Torrey Bot. Club 34: 422. 1907.

Type: Nebraska, Rush Creek, Deuel County, P. A. Rydberg 82c, 2 July 1891; holotype NY!; isotypes MIN!, NEB!

= *Oxytropis lambertii* Pursh var. *lambertii*

*Aragallus arcticus* (R. Brown) Greene, Pittonia 3: 211. 1897.

Basionym: *Oxytropis arctica* R. Brown

= *Oxytropis arctica* R. Brown

*Aragallus argophyllus* Rydberg, Mem. N. Y. Bot. Gard. 1: 255. 1900.

Type: Little Blackfoot River, Montana, J. G. Cooper s.n., 1860; holotype NY!; isotype GH! (frag), US!

= *Oxytropis besseyi* (Rydberg) Blankinship var. *argophylla* (Rydberg) Barneby

*Aragallus articulatus* Greene, Proc. Biol. Soc. Wash. 18: 13. 1905.

Type: Between Fort Smith and the Rio Grande [Oklahoma or western Texas], J. M. Bigelow s.n., 1853; holotype US!

= *Oxytropis lambertii* Pursh var. *lambertii*

*Aragallus atropurpureus* Rydberg, Bull. Torrey Bot. Club 34: 424. 1907.

Type: Headwaters of the Tongue River, Big Horn Mountains, Wyoming, F. Tweedy 125, 126, 1898; cotypes NY!

= *Oxytropis lagopus* Nuttall var. *atropurpureus* (Rydberg) Barneby

*Aragallus aven-nelsonii* Lunell, Bull. Leeds Herb. 2: 6. 1908.

Type: North Dakota, Butte, Benson County, J. Lunell s.n., 14, 21 June, 2 July 1908; isotypes NY!, US!, WTC, MIN!, NDA!

= *Oxytropis lambertii* Pursh var. *lambertii*

*Aragallus bellii* (Britton) Greene, Pittonia 3: 212. 1897.

Basionym: *Spiesia Oxytropis bellii* Britton

= *Oxytropis arctica* R. Brown var. *bellii* (Britton) Boivin

*Aragallus besseyi* Rydberg, Mem. N. Y. Bot. Gard. 1: 250. 1900.

- Type: Montana, Spanish Basin, Gallatin County, 6,500 ft., P. A. Rydberg & E. A. Bessey 4501, 23 June 1897; holotype NY!; isotypes GH!, NDG!, US!  
 = *Oxytropis besseyi* (Rydberg) Blankinship var. *besseyi*
- Aragallus bigelovii* (A. Gray) Greene, Pittonia 3: 212. 1897.**  
 Basionym: *Oxytropis lambertii* Pursh var. *bigelovii* A. Gray  
 = *Oxytropis lambertii* Pursh var. *lambertii*
- Aragallus blankinshipii* A. Nelson, Erythea 7: 58. 1899.**  
 Type: Montana, dry rocky hillsides along Middle Creek, 15 mi SW of Bozeman, Gallatin County, J. W. Blankinship s.n., 4 July 1898; holotype RM!; isotypes GH!, NY!  
 = *Oxytropis lagopus* Nuttall var. *lagopus*
- Aragallus bryophilus* Greene, Proc. Biol. Soc. Wash. 18: 17. 1905.**  
 Type: Alaska, St. Matthew Island, J. M. Macoun 18510, 10 July 1891; holotype NDG!  
 = *Oxytropis nigrescens* (Pallas) Fischer var. *nigrescens*
- Aragallus campestris* (L.) de Candolle var. *johannensis* Fernald ex Macoun, Ottawa Nat. 13: 163. 1899, nomen.**  
 Basionym: *Oxytropis campestris* (L.) de Candolle var. *johannensis* Fernald  
 = *Oxytropis campestris* (L.) de Candolle var. *johannensis* Fernald
- Aragallus caudatus* Greene, Pittonia 4: 69. 1899.**  
 Type: Saskatchewan, Moose Jaw, J. M. Macoun 13957, 26 June 1896; holotype NDG!; isotype CAN!  
 = *Oxytropis splendens* Douglas
- Aragallus cervinus* Greene, Proc. Biol. Soc. Wash. 18: 16. 1905.**  
 Type: British Columbia, Deer Park, Lower Arrow Lake, J. M. Macoun 5358, 8 June 1890; holotype NDG!  
 = *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby
- Aragallus collinus* A. Nelson, Erythea 7: 57. 1899.**  
 Type: Wyoming, Seminoe Mts., Carbon County, E. Nelson 4925, 21 July 1898; holotype RM!; isotypes GH!, NY!, US!  
 = *Oxytropis nana* Nutt.
- Aragallus deflexus* (Pallas) A. A. Heller, Cat. N. Amer. Pl., 4. 1898.**  
 Basionym: *Astragalus deflexus* Pallas  
 = *Oxytropis deflexa* (Pallas) de Candolle
- Aragallus dispar* A. Nelson, Erythea 7: 61. 1899.**  
 Type: North Dakota, Dickinson, Stark County, Mrs. Cook s.n., 1896; holotype RM!; photo BRY!  
 = *Oxytropis campestris* (L.) de Candolle var. *dispar* (A. Nelson) Barneby
- Aragallus falcatus* Greene, Proc. Biol. Soc. Wash. 18: 13. 1905.**  
 Type: Missouri, Watson, Atchison County, B. F. Bush 204, 1 June 1894; holotype NDG!; isotypes GH!, NY!, US!, ISC!, MIN!, MO!, DAO! (Note: The same collection is also the type of *Oxytropis bushii* Gandoger.)  
 = *Oxytropis lambertii* Pursh var. *lambertii*
- Aragallus foliolosus* (Hooker) Macoun, Ottawa Naturalist 13: 163. 1899.**  
 Basionym: *Oxytropis foliolosa* Hooker  
 = *Oxytropis deflexa* var. *foliolosa* (Hooker) Barneby
- Aragallus formosus* Greene, Proc. Biol. Soc. Wash. 18: 13. 1905.**  
 Type: South Dakota, Fort Meade, Meade County, W. H. Forwood 95, 7 June 1887; holotype US!, photo BRY!  
 = *Oxytropis lambertii* Pursh var. *lambertii*
- Aragallus galioides* Greene, Proc. Biol. Soc. Wash. 18: 16. 1905.**  
 Type: Alberta, Bow River near Banff, McCalla s.n., 10 July, 18 September 1899; holotype US!  
 = *Oxytropis splendens* Douglas
- Aragallus gracilis* A. Nelson, Erythea 7: 60. 1899.**  
 Type: Wyoming, Limestone Range, Newcastle, Weston County, A. Nelson 2545, 30 July 1896; holotype RM!; isotypes GH!, NY!, US!  
 = *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby
- Aragallus hallii* (Bunge) Rydberg, Bull. Torrey Bot. Club 33: 144. 1906.**  
 Basionym: *Oxytropis hallii* Bunge  
 = *O. podocarpa* A. Gray
- Aragallus hudsonicus* Greene, Proc. Biol. Soc. Wash. 18: 17. 1905.**  
 Type: Canada, Whale River, Hudson Bay; A. P. Low 14272, 24 June 1896; holotype NDG!; isotype GH!, S!  
 = *Oxytropis borealis* de Candolle var. *hudsonica* (Greene) Welsh  
 The specimen at Stockholm has information identical to that at GH, except that the collection is attributed to Spreadborough.
- Aragallus inflatus* (Hooker) A. Nelson, Erythea 7: 59. 1899.**  
 Basionym: *Oxytropis arctica* ♂ *inflata* Hooker  
 = *Oxytropis podocarpa* A. Gray
- Aragallus invenustus* Greene, Proc. Biol. Soc., Wash. 18: 12. 1905.**  
 Type: South Dakota, about Fort Meade, Meade County, W. H. Forwood 96a, 96b, 3 June 1887, 96b, 7 June 1887; cotypes US!, photo BRY!  
 = *Oxytropis sericea* Nuttall var. *sericea*
- Aragallus involutus* A. Nelson, Erythea 7: 64. 1899.**  
 Type: Minnesota, Acton, Meeker County, W. D. Frost s.n., June 1892; holotype RM!; isotypes MIN!, MO!, US!  
 = *Oxytropis lambertii* Pursh var. *lambertii*
- Aragallus johannensis* (Fern.) A. Heller, Cat. N. Amer. Pl., ed 2: 7. 1900.**  
 Basionym: *Oxytropis campestris* (L.) de Candolle var. *johannensis* Fernald  
 = *Oxytropis campestris* (L.) de Candolle var. *johannensis* Fernald
- Aragallus knowltonii* Greene, Proc. Biol. Soc. Wash. 18: 12. 1905.**  
 Type: Arizona, San Francisco Mountains, Coconino County, F. H. Knowlton 44, 20 August 1889; holotype US!  
 = *Oxytropis lambertii* Pursh var. *bigelovii* A. Gray

*Aragallus lagopus* (Nuttall) Greene, Pittonia 3: 212. 1897.

Basionym: *Oxytropis lagopus* Nuttall

*Aragallus lambertii* (Pursh) Greene, Pittonia 3: 212. 1897.

Basionym: *Oxytropis lambertii* Pursh

var. *sericeus* (Nuttall) A. Gray, Proc. Amer. Acad. 20: 7. 1884.

Basionym: *Oxytropis sericea* Nuttall

*Aragallus luteolus* Greene, Proc. Biol. Soc. Wash. 18: 17. 1905.

Type: Washington, Olympic Mts., Clallam County, A. D. Elmer 2532, July 1900; holotype US!; isotypes NE, NY!, NDG!, MIN!, MO!, WTC, CAS!, DS!

= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Aragallus majusculus* Greene, Proc. Biol. Soc. Wash. 18: 12. 1905.

Type: Utah, Henry Mts., Garfield County, Utah, M. E. Jones 5674, July 1894; holotype US!; isotype NY!, MO!, photo BRY!

= *Oxytropis sericea* Nuttall var. *sericea*

*Aragallus macounii* Greene, Proc. Biol. Soc. Wash. 18: 16. 1905.

Type: Alberta, Elbow River, Rocky Mountains, Lat. 49°40', J. M. Macoun 18517, June–July 1897; holotype NDG!

= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

Two specimens, J. M. Macoun 18516 and 18517, were cited as type of *Aragallus macounii* Greene. Barneby (1952) designated 18517 as the type of the taxon; the other specimen belongs to *O. sericea* Nuttall var. *spicata* (Hooker) Barneby.

*Aragallus melanodontus* Greene, Proc. Biol. Soc. Wash. 18: 15. 1905.

Type: Alberta, Elbow River, Rocky Mountains, Lat. 49°40', J. M. Macoun 18513, June–July 1897; holotype NDG!

= *Oxytropis sericea* Nuttall var. *spicata* (Hooker) Barneby

*Aragallus mertensianus* (Turczaninow) Greene, Pittonia 3: 211. 1897.

Basionym: *Oxytropis mertensiana* Turczaninow

= *Oxytropis mertensiana* Turczaninow

*Aragallus metcalfei* Greene, Proc. Biol. Soc. Wash. 18: 12. 1905.

Type: New Mexico, Sawyer's Peak, Grant County, open glade, ca 10,000 ft., O. B. Metcalf 1079, 7 July 1904; holotype US!; isotypes NY!, CAS!, GH!, POM, WTC.

= *Oxytropis lambertii* Pursh var. *bigelovii* A. Gray

*Aragallus minor* (A. Gray) Cockerell ex Daniels, Univ. Missouri Sci. Stud. II, 2: 158. 1911.

Basionym: *Oxytropis multiceps* var. *minor* A. Gray

= *Oxytropis multiceps* Torrey & Gray

*Aragallus monticola* (A. Gray) Greene, Pittonia 3: 212. 1897.

Basionym: *Oxytropis monticola* A. Gray

= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Aragallus multiceps* (Torrey & Gray) A. Heller, Cat. N. Amer. Pl., 4. 1898.

Basionym: *Oxytropis multiceps* Torrey & Gray

= *Oxytropis multiceps* Torrey & Gray

var. *minor* (A. Gray) A. Nelson, Erythraea 7: 57. 1899.

Basionym: *Oxytropis multiceps* var. *minor* A. Gray

= *Oxytropis multiceps* Torrey & Gray

*Aragallus nanus* (Nuttall) Greene, Pittonia 3: 212. 1897.

Basionym: *Oxytropis nana* Nuttall

= *Oxytropis nana* Nuttall

*Aragallus oreophilus* (A. Gray) A. Nelson, Erythraea 7: 59. 1899.

Basionym: *Oxytropis oreophila* A. Gray

= *Oxytropis oreophila* A. Gray

*Aragallus parryi* (A. Gray) Greene, Pittonia 3: 211. 1897.

Basionym: *Oxytropis parryi* A. Gray

= *Oxytropis parryi* A. Gray

*Aragallus patens* Rydberg, Bull. Torrey Bot. Club 34: 421. 1907.

Type: Colorado, plains and foothills near Boulder, Boulder County, F. Tweedy 5164, 1902; holotype NY!

= *Oxytropis lambertii* Pursh var. *bigelovii* A. Gray

*Aragallus pinetorum* A. Heller, Bull. Torrey Bot. Club 26: 548. 1899.

Type: New Mexico, 11 mi SE of Santa Fe, Santa Fe County, A. A. & E. G. Heller 3751, 23 June 1897; holotype US! (?); isotypes MO!, IA!, MU!, GH!, NDG!, NY!, POM, WTC, BRY!, DS!

= *Oxytropis sericea* Nuttall var. *sericea*

var. *veganus* Cockerell, Torreya 2: 155. 1902.

Type: New Mexico, top of Las Vegas Range, on end of ridge, T. D. A. Cockerell 20, end of June 1901; holotype NY!; isotype GH!

= *Oxytropis sericea* Nuttall var. *sericea*

*Aragallus plattensis* Nuttall ex Torrey & Gray, Fl. N. Amer. 1: 340. 1838

Type: ?

= *Oxytropis lambertii* Pursh var. *lambertii*

*Aragallus podocarpus* (A. Gray) A. Nelson, Coulter & Nelson, New Man., 294. 1909.

Basionym: *Oxytropis podocarpa* A. Gray

= *Oxytropis podocarpa* A. Gray

*Aragallus richardsonii* (Hooker) Greene, Pittonia 4: 69. 1899.

Basionym: *Oxytropis splendens*  $\beta$  *richardsonii* Hooker

= *Oxytropis splendens* Douglas

*Aragallus rigens* Greene, Proc. Biol. Soc. Wash. 18: 14. 1905.

Type: Montana, Cedar Creek, 12 mi above Glendive, Dawson County, L. F. Ward s.n., 15 July 1884; holotype US!, photo BRY!

= *Oxytropis lambertii* Pursh var. *lambertii*

*Aragallus saximontanus* A. Nelson, Erythraea 7: 190. 1899, nom. nov.

Basionym: *Oxytropis lambertii* Pursh var. *ochroleuca* A. Nels.

= *Oxytropis sericea* Nuttall var. *sericea*

var. *condensatus* (A. Nelson) A. Nelson, Erythraea 7: 190. 1900.



- Basionym: *Aragallus albiflorus* var. *condensatus* A. Nelson  
 = *Oxytropis sericea* Nuttall var. *sericea*
- Aragallus sericeus* (Nuttall) Greene, Pittonia 3: 212. 1897.  
 Basionym: *Oxytropis sericea* Nuttall  
 = *Oxytropis sericea* Nuttall
- Aragallus spicatus* (Hooker) Rydberg, Mem. N. Y. Bot. Gard. 1: 251. 1900.  
 Basionym: *Oxytropis campestris*  $\delta$  *spicata* Hooker  
 = *Oxytropis sericea* Nuttall var. *spicata* (Hooker) Barneby
- Aragallus splendens* (Douglas) Greene, Pittonia 3: 211. 1897.  
 Basionym: *Oxytropis splendens* Douglas  
 = *Oxytropis splendens* Douglas
- Aragallus varians* Rydberg, Bull. N. Y. Bot. Gard. 2: 176. 1901.  
 Type: Yukon, Lewes River, J. B. Tarleton 33b, 28 June 1899; holotype US!; isotypes S!, NY!  
 = *Oxytropis campestris* (L.) de Candolle var. *varians* (Rydberg) Barneby
- Aragallus veganus* (Cockerell) Wootton & Standley, Contr. U. S. Nat. Herb. 16: 136. 1913.  
 Basionym: *Aragallus piutorum veganus* Cockerell  
 = *Oxytropis sericea* Nuttall var. *sericea*
- Aragallus ventosus* Greene, Proc. Biol. Soc. Wash. 18: 15. 1905.  
 Type: Dry ground in the valley of the North Fork of Wind River, Wyoming, W. H. Forwood 65, 12 July 1884; holotype US!; isotype GH!  
 = *Oxytropis besseyi* (Rydberg) Blankinship var. *ventosa* (Greene) Barneby
- Aragallus villosus* Rydberg, Bull. Torrey. Bot. Club 28: 36. 1901.  
 Type: Montana, Craig, Lewis and Clark County, E. N. Wilcox 378, 20 June 1900; holotype US!; isotype NY!  
 = *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby
- Aragallus viscidulus* Rydberg, Mem. N. Y. Bot. Gard. 1: 253. 1900.  
 Type: Montana, Melrose, Silver Bow County, P. A. Rydberg 2716, 6 July 1895; holotype NY!  
 = *Oxytropis borealis* de Candolle var. *viscida* (Nuttall) Welsh  
 var. *depressus* Rydberg, Mem. N. Y. Bot. Gard. 1: 253. 1900.  
 Type: Haystack Mt., Stillwater County, Montana, F. Tweedy 120; holotype NY!  
 = *Oxytropis borealis* de Candolle var. *viscida* (Nuttall) Welsh
- Aragallus viscidus* (Nuttall) Greene, Pittonia 3: 211. 1897.  
 Basionym: *Oxytropis viscida* Nuttall  
 = *Oxytropis borealis* de Candolle var. *viscida* (Nuttall) Welsh
- Astragalus albertinus* (Greene) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.  
 Basionym: *Aragallus albertinus* Greene  
 = *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby
- Astragalus albiflorus* (A. Nelson) Candoger, Bull. Soc. Bot. France 48: xiv. 1901.  
 Basionym: *Aragallus albiflorus* A. Nelson  
 = *Oxytropis sericea* Nuttall var. *sericea*
- Astragalus alpicola* (Rydberg) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.  
 Basionym: *Aragallus alpicola* Rydberg  
 = *Oxytropis campestris* (L.) de Candolle var. *eusickii* (Greenman) Barneby
- Astragalus arcticus* (R. Brown) Sprengel, Syst. 4: 288. 1827.  
 Basionym: *Oxytropis arctica* R. Brown  
 = *Oxytropis arctica* R. Brown
- Astragalus bellii* (Britton) Tidestrom, Proc. Biol. Soc. Wash. 50: 18. 1937.  
 Basionym: *Spicaria bellii* Britton  
 = *Oxytropis arctica* R. Brown var. *bellii* (Britton) Boivin
- Astragalus biflorus* Schweinitz ex Gray, Proc. Amer. Acad. 6: 234. 1864, synonym.  
 = *Oxytropis podocarpa* A. Gray
- Astragalus bisontum* Tidestrom, Proc. Biol. Soc. Wash. 50: 18. 1937.  
 = *Oxytropis multiceps* Torrey & Gray  
 var. *minor* (A. Gray) Tidestrom, Proc. Biol. Soc. Wash. 50: 18. 1937.  
 Basionym: *Oxytropis multiceps* var. *minor* A. Gray  
 = *Oxytropis multiceps* Torrey & Gray
- Astragalus blankinshipii* (A. Nelson) Tidestrom, Proc. Biol. Soc. Wash. 50: 18. 1937.  
 Basionym: *Aragallus blankinshipii* A. Nelson  
 = *Oxytropis lagopus* Nuttall
- Astragalus campestris* L., Sp. Pl., 761. 1753.  
 Type: "in Oelandia, Germania, Helvetia"; holotype LINN 926/51!  
 = *Oxytropis campestris* (L.) de Candolle
- Astragalus coronaminis* (Fernald) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1947.  
 Basionym: *Oxytropis coronaminis* (Fernald) Tidestrom  
 = *Oxytropis arctica* R. Brown var. *arctica*
- Astragalus deflexus* Pallas, Acta Acad. Sci. Imp. Petrop. 2: 268. 1779.  
 Type: "ad nivalia Dauriae . . . circa Balyra rivum aliosque Ononem influentibus" [Siberia], P. S. Pallas s.n.; holotype BM.  
 = *Oxytropis deflexa* (Pallas) de Candolle var. *deflexa*  
 var. *foliolosus* (Hooker) Tidestrom, Proc. Biol. Soc. Wash. 50: 18. 1937.  
 Basionym: *Oxytropis foliolosa* Hooker  
 = *Oxytropis deflexa* (Pallas) de Candolle var. *foliolosa* (Hooker) Barneby
- Astragalus gaspensis* (Fernald & Kelsey) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.  
 Basionym: *Oxytropis gaspensis* Fernald & Kelsey  
 = *Oxytropis borealis* de Candolle var. *viscida* (Nuttall) Welsh
- Astragalus grayanus* Tidestrom, in Tidestrom & Kittell, Fl. Ariz. & New Mex., 216. 1941, nom. nov.  
 = *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Astragalus lagopus* (Nuttall) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.

Basionym: *Oxytropis lagopus* Nuttall  
= *Oxytropis lagopus* Nuttall

*Astragalus lambertii* (Pursh) Sprengel, Syst. 3: 308. 1826.

Basionym: *Oxytropis lambertii* Pursh  
= *Oxytropis lambertii* Pursh var. *lambertii*

var. *bigelovii* (A. Gray) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.

Basionym: *Oxytropis lambertii* Pursh var. *bigelovii* A. Gray  
= *Oxytropis lambertii* Pursh var. *bigelovii* A. Gray

*Astragalus mazama* (St. John) G. N. Jones, Univ. Wash. Pub. Bot. 7: 175. 1938.

Basionym: *Oxytropis mazama* St. John.  
= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Astragalus munzii* Wheeler, Leaff. W. Bot. 2: 209. 1939, nom. nov.

= *Oxytropis oreophila* A. Gray

*Astragalus nigrescens* Pallas, Astragalogia, 65, tab. 53. 1800.

Type: "inter Aldanum fl[umen] et orientalem Oceanum" [between Aldan River and the Sea of Okhotsk, Siberia], D. D. Merk; type LE.

= *Oxytropis nigrescens* (Pallas) de Candolle

var. *arctobia* (Pallas) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.

Basionym: *Oxytropis arctobia* Pallas  
= *Oxytropis nigrescens* var. *uniflora* (Hooker) Barneby

*Astragalus oreophilus* (A. Gray) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.

Basionym: *Oxytropis oreophila* A. Gray  
= *Oxytropis oreophila* A. Gray

*Astragalus parryanus* Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1941.

nom. nov. pro *Oxytropis parryi* A. Gray  
= *Oxytropis parryi* A. Gray

*Astragalus pygmaeus* Pallas, Astragalogia, 66, tab. 54. 1800.

Type: ?  
= *Oxytropis nigrescens* (Pallas) Fischer var. *nigrescens*

*Astragalus retroflexus* Pallas, Astragalogia, 33, tab. 27. 1800.

Type: ?  
= *Oxytropis deflexa* var. *deflexa*

*Astragalus rusbyi* Green & Morris, J. Amer. Soc. Agron. 27: 546, 549, figs. 1, 2. 1935, prov. nom.

= *Oxytropis riparia* Litvinov

*Astragalus rydbergianus* Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937, nom. nov.

= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Astragalus saximontanus* (A. Nelson) Tidestrom, in Tidestrom & Kittell, Fl. Ariz. New Mex., 216. 1941.

Basionym: *Aragallus saximontanus* A. Nelson, nom. nov. *Oxytropis lambertii* Pursh var. *ochroleuca* A. Nelson  
= *Oxytropis sericea* Nuttall var. *sericea*

*Astragalus septentrionalis* Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937, substitute name.

= *Oxytropis podocarpa* A. Gray

*Astragalus splendens* (Douglas) Tidestrom, Proc. Biol. Soc. Wash. 50: 18. 1937.

Basionym: *Oxytropis splendens* Douglas  
= *Oxytropis splendens* Douglas

var. *richardsonii* (Hooker) Tidestrom, Proc. Biol. Soc. Wash. 50: 128. 1937.

Basionym: *Oxytropis splendens*  $\beta$  *richardsonii* Hooker  
= *Oxytropis splendens* Douglas

*Astragalus tomae* Tidestrom, Proc. Biol. Soc. Wash. 50: 18. 1937, nom. nov.

= *Oxytropis nana* Nuttall

*Astragalus viscidus* (Nuttall) Tidestrom, Proc. Biol. Soc. Wash. 50: 19. 1937.

Basionym: *Oxytropis viscida* Nuttall  
= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh

*Oxytropis alaskana* A. Nelson, Univ. Wyo. Pub. Bot. 1: 120. 1926.

Type: Kachemak Bay, Cook Inlet, M. W. Gorman 1560; holotype RM!; isotype WTU.

= *O. campestris* (L.) de Candolle var. *varians* (Rydberg) Barneby

*Oxytropis albertina* (Greene) Rydberg, Fl. Prair. & Pl., 484. 1932.

Basionym: *Aragallus albertinus* Greene  
= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Oxytropis albiflora* (A. Nelson) K. Schumann, Just's Bot. Jahresb. 27: 496. 1901.

Basionym: *Aragallus albiflorus* A. Nelson, nom. nov.  
*Oxytropis lambertii* Pursh var. *ochroleuca* A. Nelson  
= *O. sericea* Nuttall var. *sericea*

*Oxytropis alpicola* (Rydberg) M. E. Jones, Mont. Bot. Notes, 34. 1910.

Basionym: *Aragallus alpicola* Rydberg  
= *O. campestris* (L.) de Candolle var. *cusickii* (Greenman) Barneby

*Oxytropis angustata* (Rydberg) A. Nelson, Univ. Wyo. Pub. Bot. 1: 116. 1926.

Basionym: *Aragallus angustatus* Rydberg  
= *O. lambertii* var. *lambertii*

*Oxytropis arctica* R. Brown, Parry's First Voy., Append. 9: 278. 1824.

Type: Canada, Melville Island, Parry's First Voyage, Sabine, Edwards, Ross, and others, 1819–1820; holotype (?) SI!; isotype G!!

var. *arctica*

Distribution: Alaska, Yukon, Canadian Arctic Archipelago, N.W.T. east to north of Hudson Bay, and less commonly in the interior.

The var. *arctica* is recognizable by its racemes of mainly fewer than 8 large purple or lavender flowers on plants mainly less than 15 cm tall and leaflets not or seldom fasciculate. Mainly they occur in or near coastal Alaska and Canada; less commonly they are montane plants of the interior or occur in other interior situations.

var. *barnebyana* Welsh, Great Basin Nat. 28: 152, fig. 4. 1968.

Type: Alaska, Kotzebue, 66°55'N, 162°40'W, S.L. Welsh 5729, 1966; holotype BRY!; isotype NY!, UC!

Distribution: Coastal northwestern Alaska; endemic. Flower size, pilose stipules, and calyx features indicate an alliance to the sympatric *O. arctica*. The racemes vary from subcapitate to somewhat expanded. In the expanded form the plants are a close match for much of *O. arctica* in a strict sense. The placement of *O. arctica* var. *barnebyana* with *O. sordida*, a taxonomic entity considered by European authors (see Flora Europaea) at infraspecific level within *O. campestris*, has considerable merit. However, the treatment of var. *barnebyana* at infraspecific level within *O. sordida*, a highly variable taxonomic entity with both pale and colored flowers, by Jurtsev (1986), does not solve the basic problem of the similarity of *barnebyana* to *O. arctica*, however well that placement indicates the similarity of this North American phase with the protean *campestris* complex. The calyx teeth of var. *barnebyana* vary from short, as in some phases of *O. campestris*, to almost as long as in some phases of *O. arctica*. The sympatry of *O. arctica* and the allopatry of *O. campestris*, while not conclusive, weigh in the decision to keep the Kotzebue materials of var. *barnebyana* with *O. arctica*. And, the lack of a stopping place for additional inclusions of North American taxa within expanded versions of *campestris* or *sordida* is likewise a consideration.

ssp. *bellii* (Macoun) Love & Love, Taxon 31: 347. 1982.

Basionym: *Spiesia bellii* Britton ex Macoun  
= *O. arctica* R. Brown var. *bellii* (Britt.) Boivin

var. *bellii* (Britton) Boivin, Naturaliste Canad. 94: 73. 1967.

Basionym: *Spiesia bellii* Britton ex Macoun  
Distribution: Kewatin, vicinity of Hudson Bay, Canada; endemic.

The similarity of this large-flowered low plant of coastal or near coastal Hudson Bay and vicinity to specimens designated as var. *murrayi* is readily apparent. They also simulate closely plants from Armatkchene Island off the coast of Siberia. The latter are evidently included by Jurtsev (1986) as portions of an expanded *O. sordida*. The alliance of var. *bellii* to *O. arctica* has long been recognized. Any expansion of *O. sordida* to include it would also, logically, include the remainder of the *arctica* complex. Such a proposal is herein considered as both illogical and unnecessary.

♂ *inflata* Hooker, Fl. Bor.-Amer., 1: 146. 1834.

Type: "Without locality, '*O. arctica* comm. Hooker"; holotype ?; isotypes GH!, NY!, PH!

= *O. podocarpa* A. Gray

The specimen at GH! is accompanied by a small label bearing the notation, "*O. arctica* ♂ *inflata*." Below it in Asa Gray's handwriting is the note, "*O. podocarpa*. Plenty and same with the rather inflated legume in Hb. Kew." Below that, in the writing of a person not identified, is the notation, "Highest

summits of the Rocky Mts., Drummond." The plant is almost certainly typical material of var. *inflata*.

var. *koyukukensis* (Porsild) Welsh, Iowa State J. Sci. 41: 280. 1967.

Basionym: *O. koyukukensis* Porsild

Distribution: Umiat, Wiseman, Anaktuvuk, Koyukuk, Shatolik, and Northway vicinities, Alaska; endemic.

The specimens upon which this variety are based vary considerably. They tend to be tall plants with several flowered racemes, but they approach if not actually pass into var. *arctica* (specimens from Anaktuvuk). Leaflet arrangement ranges from entire to fasciculate to merely scattered. To the south they simulate specimens of var. *murrayi*, described by Jurtsev (1986) in *O. sordida*.

var. *murrayi* (Jurtsev) Welsh comb. nov.

Basionym: *O. sordida* var. *murrayi* Jurtsev Arctic Fl. U.S.S.R. 9(2): 179. 1986.

Distribution: St. Elias Mts., SW Yukon, Canada; endemic.

This taxon is the portion of the *arctica* complex most similar to var. *bellii*, from which it is distantly isolated, but is probably most nearly allied to the nearer disjunct, var. *koyukukensis*. Robust materials of var. *murrayi* closely simulate some of var. *koyukukensis*. The differences between vars. *murrayi* and *bellii* rest on such intangibles as the apparently larger flowers, broader calyces with mixed shaggy villous vesture, and tendency to larger leaflets of var. *murrayi*.

α *subumbellata* Hooker, Parry's Second Voy., Append. 4: 396. 1825.

Type: ?

= *O. arctica* R. Brown var. *arctica*

β *uniflora* Hooker, Parry's Second Voy., Append. 4: 396. 1825.

Type: Barrow River, E coast Melville Peninsula, lat. 67°21'N, on Parry's Second Voyage; isotypes GH!, NY!

= *O. nigrescens* (Pallas) Fischer var. *uniflora* (Hooker) Barneby

varietas *notabilis*, R. Brown, Chlor. Melvill., 254. 1823.

= *O. nigrescens* (Pallas) Fischer var. *uniflora* (Hooker) Barneby

*Oxytropis arctica* Bunge, Gen. Oxytropis, 114. 1874.

Type: ?

= *O. nigrescens* (Pallas) Fischer var. *uniflora* (Hooker) Barneby

var. *hyperarctica* Polunin, Bot. Canad. E. Arctic, 293, pl. 8. 1940.

Type: Franklin district, Baffin Island, Arctic Bay, N. Polunin 2583, 8–11 Sept. 1936; holotype CAN; isotypes GH!, BM, OXF.

= *O. nigrescens* (Pallas) Fischer var. *uniflora* (Hooker) Barneby

*Oxytropis atropurpurea* (Rydberg) A. Nelson, Univ. Wyo. Pub. Bot. 1: 117. 1928.

Basionym: *Aragallus atropurpureus* Rydberg

= *Oxytropis lagopus* Nuttall var. *atropurpurea* (Rydberg) Barneby

*Oxytropis aven-nelsonii* (Lunell) A. Nelson, Univ. Wyo. Pub. Bot. 1: 116. 1926

Basionym: *Aragallus aven-nelsonii* Lunell  
= *Oxytropis lambertii* Pursh var. *lambertii*

*Oxytropis bellii* (Britton) Palibin, Bull. Soc. Bot. Geneve II, 2: 19. 1910.

Basionym: *Spiesia bellii* Britton  
= *O. arctica* R. Brown var. *bellii* (Britton) Boivin

*Oxytropis besseyi* (Rydberg) Blankinship, Mont. Agric. Coll. Sci. Stud. Bot. 1: 80. 1904.

Basionym: *Aragallus besseyi* Rydberg

var. *argophylla* (Rydberg) Barneby, Leaf. W. Bot. 5: 111. 1951.

Basionym: *Aragallus argophyllus* Rydberg

Distribution: W Montana, adjacent Idaho, and NE Nevada.

var. *besseyi*

Distribution: Idaho, Montana, Wyoming, and Saskatchewan.

var. *fallax* Barneby, Proc. Calif. Acad. Sci. IV, 27: 235. 1952.

Type: Clay slope among boulders, 4350 ft., mouth of Shell Creek, Big Horn Mountains, Big Horn County, Wyoming, 4,350 ft., H. D. Ripley & R. C. Barneby 8010, 16 June 1946; holotype CAS!; isotypes GH!, US!, RM!

Distribution: West of the Bighorn River, Wyoming.

var. *obnapiformis* (C. L. Porter) Welsh, Great Basin Nat. 38: 337. 1978.

Basionym: *O. obnapiformis* C. L. Porter

Distribution: NW Colorado, NE Utah, and SW Wyoming.

The pod of this variety is strictly sessile or nearly so, not stipitate as in other phases of the species with inflated pods. Plants from the type locality near Mayfield, Colorado, have 13–25 leaflets and inflorescences about equaling the leaves. Those from Daggett County, Utah, have 5–9 leaflets and inflorescences surpassing the leaves. Plants from elsewhere bridge the two phases.

var. *salmonensis* Barneby, Proc. Calif. Acad. Sci. IV, 24: 234. 1952.

Type: Salmon River Canyon, 12 mi below Clayton, Custer County, Idaho, alt. 5,400 ft., H. D. Ripley & R. C. Barneby 8829, 22 June 1947; holotype CAS!; isotypes NY!, IDS.

Distribution: Custer Co., Idaho; endemic.

var. *centosa* (Greene) Barneby, Leaf. W. Bot. 5: 111. 1951.

Basionym: *Aragallus centosus* Greene

Distribution: S Montana, W Wyoming, and NE Utah.

*Oxytropis bilocularis* A. Nelson, Univ. Wyo. Pub. Bot. 1: 114. 1926

Type: Arizona, high moist slopes, Miller Peak, Huachuca Mts., Cochise County, L. N. Goodding 2411, 22 August 1907; holotype RM!; isotypes GH!, NY!, UCL, POM.

= *O. lambertii* var. *higelowii* A. Gray

*Oxytropis blankinshipii* (A. Nelson) K. Schumann, Just's Bot. Jahresh. 27: 496. 1901.

Basionym: *Aragallus blankinshipii* A. Nelson

= *O. lagopus* Nuttall var. *lagopus*

*Oxytropis borealis* de Candolle, Prodr. 2: 275. 1825.

Type locality: "In terra Tschuktschorum ad sinum Sancti-Laurentii," collector not stated. Type: "e sinu S. Laurentii in terra Tschuktschorum (pays des Tchouktschi) septentrionem versus a fretus Beringii. Legumina divisa a leg. ox. montana. m. Fischer 1825"; G-DC.!

= *O. borealis* de Candolle var. *borealis*

var. *australis* Welsh, Great Basin Nat. 50: 359. 1991.

This southern phase of *O. borealis* is mainly montane in distribution, but occurs mostly on xeric sites in sagebrush, black sagebrush, grass, ponderosa pine, and aspen parkland communities, often on exposed ridges or outcrops. Main substrate types are of igneous origin, either granitic or basaltic derived soils, but limestone also serves as a substrate. Elevational range varies from 2135 to 3355 m.

Distribution: Inyo and Mono counties, California, Nevada, and S Utah.

β Hooker & Arnott, Bot. Beechey Boy., 122. 1832.

Type: ?

= *Oxytropis borealis* de Candolle var. *borealis*

var. *borealis*

Distribution: N.W.T., Yukon, and Alaska; Chukotsk. The relatively few leaflets, ample flowers, and condensed, copiously hirsute inflorescence in combination allow this entity to be rather readily identified. It consists, at least in part, of what has passed under the name of *O. glutinosa* Porsild, who excluded the type of "*subsucculenta*" from consideration in treatment of the genus in "Vascular Plants of Continental Northwest Territories Canada" (Porsild & Cody 1979). Included within the concept of var. *borealis* is the *O. uralensis* β *subsucculenta* Hooker, the basis of *O. viscida* var. *subsucculenta* (Hooker) Barneby.

var. *hudsonica* (E. Greene) Welsh, Great Basin Nat. 50: 357. 1991.

Basionym: *Aragallus hudsonicus* E. Greene, Proc. Biol. Soc. Wash. 18: 17. 1905.

Distribution: Yukon east to Hudson Bay.

This is the phase of the species that occurs in North America mainly east of the Yukon, but with some representation in that province, where it is transitional with both var. *viscida* and var. *sulphurea*.

var. *sulphurea* (Porsild) Welsh, Great Basin Nat. 50: 358. 1991

Basionym: *Oxytropis viscidula* ssp. *sulphurea* Porsild, Bull. Nat. Mus. Can. 121: 247. 1951. Includes: *O. verruculosa* Porsild.

Distribution: British Columbia, Yukon, and E Alaska. These are the pallid-flowered plants of the Yukon and Alaska. In their most typical condition the racemes are compactly and uniformly small flowered. They vary from that norm to elongate racemes with small to large flowers. The bracts are mainly small, but in some they are very long and conspicuous in the inflorescence. On the one side the plants seem to grade with var. *hudsonica* and on the other with both var. *viscida* and var. *borealis*.

var. *viscida* (Nuttall) Welsh, Great Basin Nat. 50: 359. 1991.

Basionym: *O. viscida* Nuttall, ex Torrey & Gray, *Flora N. Amer.* 1: 341, 1838.

Distribution: Alaska, Yukon, N.W.T., Gaspe, British Columbia, Alberta, Minnesota, Oregon, Idaho, Wyoming, Nevada, Utah, Colorado, and California.

This variety includes almost as much diversity as the species as a whole. The numerous subunits are held together by tenuous characteristics that are difficult to define or place in a key. Variation is often great in populations from adjacent hillsides or on a single gravel bar, especially in the Arctic. One is reminded of the conditions of morphological variation occurring in the boreal *O. nigrescens* var. *nigrescens*, as treated by this author. Unless one is willing to support a taxonomy wherein the purported taxa are largely sympatric and consist of morphological subunits whose genetic continuity is questionable, made up of a series of similar plants held together by that similarity and not by genetic linkage, there does not seem to be a reasonable way to segregate the morphological variation as taxa. The rather large number of synonyms, often at specific or varietal level, reflects the attempts at segregation.

*Oxytropis bushii* Gandoger, *Bull. Soc. Bot. France* 48: xvii, 1901.

Type: Missouri, Watson, Atchison County, B. F. Bush 204, 7 June 1894; isotypes GH!, NDC, ISC! NY!, US!, MN!, MO!

= *O. lambertii* var. *lambertii*

*Oxytropis campestris* (L.) de Candolle, *Astragalologia*, 59, 1802.

Basionym: *Astragalus campestris* L.

var. *americana* Brunet, *Cat. Pl. Canad.*, 39, 1865, nomen.

= *O. campestris* (L.) de Candolle var. *johannensis* Fernald

var. *cervinus* (Greene) Boivin, *Naturaliste Canad.* 94: 75, 1967.

Basionym: *Aragallus cervinus* Greene

= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

var. *chartacea* (Fassett) Barneby, *Proc. Calif. Acad.* IV, 27: 269, 1952.

Basionym: *O. chartacea* Fassett

Distribution: Known only from lake shores in central and NW Wisconsin; endemic.

Plants with other of the syndrome of characteristics of var. *johannensis* in Ontario (Farn River area) also have short pods as in var. *chartacea*. These have not been examined in the field, and it seems best not to relegate this otherwise Wisconsin endemic to synonymy until more study has been completed.

var. *columbiana* (St. John) Barneby, *Leaff. W. Bot.* 5: 111, 1951.

Basionym: *O. columbiana* St. John

Distribution: Columbia River above the mouth of the Spokane River, NE Washington (where possibly extirpated), and forested margin of Flathead Lake, Montana.

This variety is characterized by its white to ochroleous flowers with maculate keel tips and soft pubescence. It is still extant at Flathead Lake.

var. *cusickii* (Greenman) Barneby, *Leaff. W. Bot.* 5: 111, 1951.

Basionym: *O. cusickii* Greenman

Distribution: British Columbia, Alberta, Washington, Oregon, Idaho, Montana, Wyoming, Utah, and Colorado.

This taxon is highly variable in flower size, especially where the large-flowered *O. sericea* var. *spicata* occurs nearby. Transitionally apparent populations again demonstrate the lack of consistent diagnostic features to separate what are otherwise distinctive populations. The same problem is apparent where var. *gracilis* occurs nearby at lower elevations than these montane phases of the *campestris* complex (see also var. *varians*).

var. *darisii* Welsh, *Leaff. W. Bot.* 10: 25, 1963.

Type: British Columbia, mi 403.4, Alaska Hwy., R. J. Davis 6076, 19 July 1962; holotype BRY!, isotype IDS!

Distribution: SW Alberta, NE British Columbia.

This plant is readily distinguished by its colorful flowers, fasciculate leaflets or tendency to fasciculate leaflets, and elongate inflorescences. Specimens have been known in collections from early times, but have been regarded as occasional intermediates between portions of the *campestris* complex and *O. borealis* var. *viscida*, or, they have been identified, because of the fasciculate leaflets, as *O. splendens*. The plants are locally abundant on stream gravels and adjacent slopes in the foothills mainly of the Alberta Rockies and in northeast British Columbia. The plants form apparent intermediates with var. *gracilis*.

var. *dispar* (A. Nelson) Barneby, *Leaff. W. Bot.* 5: 111, 1951.

Basionym: *Aragallus dispar* A. Nelson

Distribution: North Dakota and Manitoba.

Plants of this variety are closely allied to var. *gracilis*, from which they differ in the flowers being polychrome in populations, and in the somewhat firmer texture of the pods. It may well be that var. *dispar* is the somewhat stabilized product of previous hybridization involving the mainly disjunct pale-flowered var. *gracilis* and the now far disjunct purple-flowered vars. *darisii* and *johannensis*. Purple-flowered or polychrome populations or entire taxa within the *campestris* complex are now known to be at least as important as are the pale-flowered phases. Indeed, pink-purple flowers show up here and there throughout North America, even in otherwise white or ochroleucous populations.

var. *glabrata* Hooker, *Fl. Bor.-Amer.* 1: 147, 1834.

Type: Bear Lake to the Arctic Shores and Islands [possibly Richardson]; isotype (?) GH!

= *O. maydelliana* Trautvetter

ssp. *gracilis* (A. Nelson) Boivin, *Naturaliste Canad.* 94: 74, 1967.

Basionym: *Aragallus gracilis* A. Nelson

= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

var. *gracilis* (A. Nelson) Barneby, *Leaff. W. Bot.* 5: 111, 1951.

Basionym: *Aragallus gracilis* A. Nelson

Distribution: Mainly south of the 65th parallel in British Columbia, Alberta, Saskatchewan, Manitoba, Washington, Montana, Wyoming, South Dakota, North Dakota, and Colorado.

This is a highly variable taxon whose morphological subunits have been regarded by some previous workers as belonging to several specific or infra-specific taxa. A portion of the problem revolves around the inclusion of materials with two different base chromosome numbers, 32 and 48. At least some portion of it is the southern counterpart of var. *varians*, which is reported to have the base chromosome number of 48. The variety is transitional to var. *darvisii* in southwestern Alberta, to var. *dispar* in North Dakota, and more especially to the montane var. *cusickii*, which often occurs at the tops of the same mountains whose bases bear var. *gracilis*.

var. *johannensis* Fernald, Rhodora 1: 88. 1899.

Type: Maine, gravelly shores, valley of St. John River, Fort Kent, Aroostook County. M. L. Fernald 2289, 15 June 1898; holotype GH!; isotype CAN!, US!, NY!

Distribution: Newfoundland, New Brunswick, Nova Scotia, Quebec, Ontario, and Maine.

Plants of this variety from the Farm River area, south of James Bay, Ontario, have fasciculate leaflets and short pods. In the latter feature they simulate the var. *chartacea*, which might best be regarded as only a disjunct phase of this variety.

ssp. *jordalii* (Porsild) Hulten, Ark. Bot. 7: 79. 1967.

Basionym: *O. jordalii* Porsild

= *O. campestris* (L.) de Candolle var. *jordalii* (Porsild) Welsh

var. *jordalii* (Porsild) Welsh, Leaf. W. Bot. 10: 25. 1963.

Basionym: *O. jordalii* Porsild

Distribution: N. Alaska, N. Yukon, and N.W.T., Mackenzie District.

This is a dwarf boreal variety of ridge tops, gravel bars, and arctic tundra with small white to ochroleucous flowers. It is easily recognizable in its typical phases, but it passes by degree, especially in lower elevation and more mesic sites into var. *varians*. On some gravel bars, especially, the plants are transitional with the other dwarf boreal var. *roaldii*. It is with the latter variety, with pink-purple flowers, that it seems to be most closely allied.

var. *ξ melanocephala* Hooker, Fl. Bor.-Amer. 1: 147. 1834.

Type: Bear Lake to the Arctic Shores and Islands [possibly Richardson]; isotype (?) GH.

= *O. maydelliana* Trautvetter

var. *roaldii* (Ostenfeld) Welsh, comb. et stat. nov.

Basionym: *O. roaldii* Ostenfeld, Vasc. pl. Arct. N. Amer. Gjoa Exped., 54, pl. 3, fig. 16. 1910.

Distribution: N. Alaska, N. Yukon, and adjacent N.W.T.

The type of this variety was included in the synonymy of *O. arctica* by Barneby (1952), whose experience with boreal representatives was limited by the few specimens available to him. The type specimen was taken on Herschell Island on the Amundsen Gjoa Expedition and is clearly the same as plants

that occur inland in northern Yukon Territory and west in Alaska to Prudhoe Bay and beyond. The variety is characterized by its small pink-purple flowers and other features that simulate and pass into the partially sympatric var. *jordalii*. The var. *roaldii* further simulates and is probably allied to the eastern var. *terrae-novae*.

var. *rydbergii* (A. Nelson) R. J. Davis, Madrono 11: 144. 1951.

Basionym: *O. rydbergii* A. Nelson

= *O. campestris* (L.) de Candolle var. *cusickii* (Greenman) Barneby

β *speciosa* Torrey & Gray, Fl. N. Amer. 1: 341. 1838.

Type: "Dr. Hooker" NY!. See Flora Boreali-Americana 1: 147. 1833. "Carleton House Saskatchewan to Rocky Mts. [T.] Drummond." The sheet at NY bears the notation quoted above and the initials E. P. S[heldon].

= *O. sericea* Nuttall var. *spicata* (Hooker) Barneby

δ *spicata* Hooker, Fl. Bor.-Amer. 1: 174. 1834.

Type: Between Carlton House on the Saskatchewan and the Rocky Mountains [Alberta]. T. Drummond s.n.; holotype ?; ? isotypes GH, NY!

= *O. sericea* Nuttall var. *spicata* (Hooker) Barneby

var. *terrae-novae* (Fernald) Barneby, Proc. Calif. Acad. IV, 27: 266. 1952.

Basionym: *O. terrae-novae* Fernald

Distribution: Hudson Bay, Baffin Island, Ungava Peninsula, Labrador, and coastal Newfoundland.

Reports of this taxon from the Mackenzie Mountains are probably of the purple-flowered var. *roaldii*, which is a western vicariat of var. *terrae-novae* that differs in minor but consistent ways. At Churchill, Manitoba, there is a mixture of specimens variously assigned to vars. *varians*, *terrae-novae*, or *johannensis*. They should be viewed in the field prior to an attempt to resolve their relationships.

var. *varians* (Rydberg) Barneby, Proc. Calif. Acad. IV, 27: 253. 1952.

Basionym: *Aragallus varians* Rydberg

Distribution: Alaska, Yukon, N.W.T., N. Manitoba, and N. British Columbia, mainly north of the 65th parallel.

Plants of this variety are highly variable, with numerous differing morphological phases often growing together on the same gravel bar in portions of Alaska and the Yukon. Alpine portions of the variety, especially in SW Yukon, N. British Columbia, and adjacent SE Alaska, closely simulate high-altitude materials of *O. campestris* var. *cusickii* at its northern limits in S. British Columbia and Alberta. Indeed, there are specimens of *O. campestris* var. *gracilis*, the so called "*cerminus*" phase in southern British Columbia, that almost match the "*alaskana*" materials of var. *varians* from southern Alaska. The maintenance of var. *varians* as separate from var. *gracilis* rests mainly on allopatry and historical perspective. Specimens of var. *varians* appear to intergrade with those of var. *jordalii* in montane sites near Juneau, Alaska.

var. *terrucosa* Ledebour, Fl. Ross. 1: 591. 1842.

Type: "in terra Tschuktschorum ad sinum Sancti-Laurentii," collector not stated, but probably

based on the type of *O. borealis* (q.v.).

= *O. borealis* de Candolle var. *borealis*

var. *riscida* (Nuttall) S. Watson, U.S. Geol. Expl. 40th Parallel, Bot. 5: 55, 1871.

Basionym: *O. riscida* Nuttall

= *O. borealis* de Candolle var. *riscida* (Nuttall) Welsh var. *vanapum* Joyal, Great Basin Naturalist 50: 373, 1991.

Type: Washington, Saddle Mt. above Lower Carh Creek, E. Joyal 12643, 25 May 1987; holotype US!; isotypes BRY!, ISC!, OSU!

Distribution: Known only from the type locality.

This is a plant of xeric, basaltic talus; the flowers suffused with purple are diagnostic, since no other phases of the genus in the Pacific Northwest typically have colored flowers. The narrow leaflets tend to be involute and to vary in number from 20 to 25. These vegetative features are unlike any of the other several varieties of *O. campestris* that occur elsewhere in North America having lavender to purplish flowers.

***Oxytropis cascadeensis* St. John**, Proc. Biol. Soc. Wash. 41: 105, 1928.

Type: Washington, Grouse Creek, Mt. Baker, Whatcom County, St. John 5513; holotype WTC!; photo BRY!

= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

***Oxytropis caudata* (Greene) K. Schumann**, Just's Bot. Jahresb. 27: 496, 1901.

Basionym: *Aragallus caudatus* Greene

= *O. splendens* Douglas

***Oxytropis chartacea* Fassett**, Rhodora 38: 95, 1936.

Type: Wisconsin, sandy shore of Lake Huron, Plainfield, Waushara County, N. C. Fassett 16704, 15 Sept. 1936; holotype WIS!; isotypes GH!, ISC!, MO!, LA!, GH!, NY, MU!, NY!, PH!, US!, UC!, DAO!

= *O. campestris* (L.) de Candolle var. *chartacea* (Fassett) Barneby

***Oxytropis collina* (A. Nelson) K. Schumann**, Just's Bot. Jahresb. 27: 496, 1901.

Basionym: *Aragallus collinus* A. Nelson

= *O. nana* Nuttall

***Oxytropis columbiana* St. John**, Proc. Biol. Soc. Wash. 41: 100, 1928.

Type: Gravelly beach of the Columbia River, Marcus, Stevens County, H. St. John 6482, 27 June 1924; holotype WTC; isotype GH!

= *O. campestris* (L.) de Candolle var. *columbiana* (St. John) Barneby

***Oxytropis condensata* (A. Nelson) A. Nelson**, Univ. Wyo. Pub. Bot. 1: 115, 1926.

Basionym: *Aragallus albiflorus* var. *condensatus* A. Nelson

= *O. sericea* Nuttall var. *sericea*

***Oxytropis coronaminis* Fernald**, Rhodora 30: 151, pl. 175, 1928.

Type: Mackenzie, Arctic sea-coast, Dr. Richardson s.n.; holotype GH!

= *Oxytropis arctica* R. Brown var. *arctica*

***Oxytropis cusickii* Greenman**, Erythra 7: 116, 1899.

Type: Oregon, alpine summits of the Willowa Mountains, W. C. Cusick 1365, 2095, 23 August 1886; lectotype (Eliscens & Packer, Canad. J. Bot. 58: 1827, 1980) GH!; Cusick 2095, Aug. 1898, syntypes GH!, NY!, NDG!, UC, US!

= *O. campestris* (L.) de Candolle var. *cusickii* (Greenman) Barneby

***Oxytropis czukotica* Jurtsev**, Bull. Mosk. Oblst. Icp. Priir., Otd. Biol. 85, 6: 102, 1980.

nom. nov. pro *O. tschuktschorum* Jurtsev

= *O. nigrescens* (Pallas) Fischer var. *nigrescens*

***Oxytropis deflexa* (Pallas) de Candolle**, Astragalologia, 33, tab. 27, 1802.

Type: "ad nivalia juga Dauria . . . in excelsis montibus circa balyra rivum aliosque Ononem influentibus" [Siberia], S. P. Pallas s.n.; holotype BM.

var. *capitata* Boivin, Svensk Bot. Tidskr. 56: 499, 1962.

Type: Ontario, cordon gazonnant le long d'une riviere, 34 mi au sud du cap Henriette, 44°54'N, A. Dutilly & E. Lepage 34367, 17 Aout 1953; holotype DAO!

= *O. deflexa* var. *foliolosa* (Hooker) Barneby

var. *culminis* Jepson, Fl. Calif. 2: 381, 1936.

Type: Cottonwood Creek, White Mts., Mono Co., California, V. Duran 1650, 29 June 1926; holotype UC!

= *O. deflexa* var. *sericea* Torrey & Gray

var. *deflexa*

Distribution: Colorado, Utah, and reported (Barneby 1952) less commonly elsewhere in North America; Asia.

As interpreted by me and by Barneby (1952), plants similar to the typical Siberian material of the species occur disjunctly in America, mainly in the mountains of Colorado and Utah. The combination of racemes with 10 to 20 large flowers on plants that are mainly acaulescent or short caulescent forms a distinctive morphology. They differ from var. *foliolosa* in about the same manner that that variety differs from var. *sericea*.

var. *dezhevii* Jurtsev, Bot. Journ. 57: 6, 647, 1972.

Type: ?

= *O. deflexa* var. *foliolosa* (Hooker) Barneby

The placement of this plant with var. *foliolosa* is based on examination of authentic material of the proposed entity in the herbarium at BRY. The specimens examined from western Alaska are somewhat more apparently black hairy than materials from farther east. Otherwise they seem to fit within the broad concept of var. *foliolosa*.

ssp. *dezhevii* (Jurtsev) Jurtsev, Arctic Fl. S.S.S.R. 9: 79, 1986.

Basionym: *O. deflexa* var. *dezhevii* Jurtsev

var. *foliolosa* (Hooker) Barneby, Leaf. W. Bot. 6: 111, 1951.

Basionym: *Astragalus deflexus* Pallas

Distribution: Rocky Mountains, from Alaska to Nevada and Wyoming; also on arctic and subarctic shores of Mackenzie, Ungava Peninsula, Baffin Island, Labrador, Newfoundland, and Gaspe Peninsula.

This is the most showy of the two common phases of the species in North America. The flowers are typically brightly colored in compact to subcompact racemes with up to 10 flowers. Sometimes there are more flowers in rather lax racemes, but the racemes seldom surpass 10 cm long even in fruit. The herbage is typically sparingly pilose and green in aspect, and both caulescent and acaulescent phases occur. Some of the variation, especially portions of that regarded as var. *capitata* Boivin, is geographically correlated. Further segregation, however, seems unnecessary. Transitional specimens to var. *sericea* are known.

var. *parviflora* Boivin, Svensk Bot. Tidskr. 56: 498. 1962.

Type: Alberta, Ft. Smith, 1 mi SW, black sandy soil in *Populus* spp., *Salix* spp., *Picea glauca* woods along trail, W. J. Cody & C. C. Loan 4496, 17 July 1950; holotype DAO!; isotype RM!

= *O. deflexa* (Pallas) de Candolle var. *sericea* Torrey & Gray

ssp. *retrorsa* (Fernald) Love & Love, Taxon 31: 347. 1982.

Basionym: *O. retrorsa* Fernald

= *O. deflexa* var. *sericea* Torrey & Gray

β [var.] *sericea* Torrey & Gray, Fl. N. Amer. 1: 242. 1838.

Type: "Rocky Mountains near streams" [Wyoming or Idaho], T. Nuttall s.n., 1834; holotype NY!

Distribution: Alaska, Yukon, N.W.T., British Columbia, Alberta, Manitoba, Washington, California, Idaho, Montana, New Mexico, Oregon, Utah, and Wyoming.

This is the common phase of *O. deflexa* south of the Arctic. The variety is highly variable, especially in size and aspect of the flowers. The small-flowered phase of the northern Rockies was proposed as var. *parviflora* Boivin. Flowers of some of the variants appear not to open, as if they are cleistogamous. Further work is indicated on this group.

*Oxytropis dispar* (A. Nelson) K. Schumann, Just's Bot. Jahresh. 27: 496. 1901.

Basionym: *Aragallus dispar* A. Nelson

= *O. campestris* (L.) de Candolle var. *dispar* (A. Nelson) Barneby

*Oxytropis falcata* (Greene) A. Nelson, Univ. Wyo. Pub. Bot. 1: 118. 1926.

Basionym: *Aragallus falcatus* Greene

= *O. lambertii* var. *lambertii*

*Oxytropis foliolosa* Hooker, Fl. Bor.-Amer. 1: 146. 1831.

Type: "Carlton House to the Rocky Mountains, in lat. 54°" [Alberta], collector not noted, probably T. Drummond; holotype K; isotype NY!

= *O. deflexa* var. *foliolosa* (Hooker) Barneby

*Oxytropis gaspensis* Fernald & Kelsey, Rhodora 30: 123. 1928.

Type: Quebec, Gaspé County, dry talus of slaty cliffs, northern face of Mt. St. Pierre, at mouth of Rivière a Pierre, M. L. Fernald & L. B. Smith 25874, 14 August 1923; holotype G!1; isotypes M!1, CAS!, NY!

= *O. borealis* de Candolle var. *riscida* (Nuttall) Welsh

*Oxytropis glaberrima* Hultén, Bot. Tidskr. 5: 124. 1954.

Type: Alaska, Kurupa Valley, 7 mi N of Kurupa Lake, A. R. Hodgdon 8060, 25 June 1952; holotype S!

= *O. nigrescens* (Pallas) Fischer var. *nigrescens*

*Oxytropis glabrata* (Hooker) A. Nelson, Univ. Wyo. Pub. Bot. 1: 117. 1926

Basionym: *O. campestris*  $\epsilon$  *glabrata* Hooker.

= *O. maydeliana* Trautvetter

*Oxytropis glutinosa* Porsild, Bull. Nat. Mus. Canad. 121: 240. 1951.

Type: Yukon, Canol Rd.: Mile 132. Lower Lapie Crossing, dry shaly slopes of mountain west of road, A. E. Porsild & A. J. Breitung 9730, 20 June 1944; holotype CAN; isotypes GH!, ISC!, S!, NY!, US!

= *O. borealis* de Candolle var. *riscida* (Nuttall) Welsh

*Oxytropis gorodkovii* Jurtsev, Bot. Journ. 53: 11. 1968 (nom. nov. pro *Astragalus pygmaeus* Pallas; *O. pygmaea* [Pallas] Fernald).

= *O. nigrescens* (Pallas) Fischer var. *nigrescens*

*Oxytropis gracilis* (A. Nelson) K. Schumann, Just's Bot. Jahresh. 24: 496. 1901.

Basionym: *Aragallus gracilis* A. Nelson

= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Oxytropis hallii* Bunge, Gen. Oxytropis, 162. 1874.

Type: Rocky Mts., Lat. 39°–41°, E. Hall & H. Harbourn 143 (in part), 1862; isotypes GH!, NY (in packet!), US!

= *O. podocarpa* A. Gray

*Oxytropis hookeriana* Nuttall ex Torrey & Gray, Fl. N. Amer., 340. 1838

Type: "O. hookeri. *O. lambertii* Hook. Platte Plains. T. Nuttall"; holotype BM.

= *O. lambertii* var. *lambertii*

*Oxytropis huddlesonii* Porsild, Bull. Nat. Mus. Canad. 121: 242. pl. 17, fig. 5. 1951.

Type: Yukon, Golden Horn Mountain, south of Whitehorse, in lichen heath above timberline, elevation 5,800 feet, C. W. Huddleson s.n. 1944; holotype CAN!

Distribution: S and E Alaska, S Yukon, and N British Columbia; endemic.

The presence of milocular, glabrous or sparingly strigose pods distinguishes this entity from *O. nigrescens*, its apparent close ally in boreal northwestern North America.

*Oxytropis hudsonica* (Greene) Fernald, Rhodora 30: 142, pl. 172. 1928.

Basionym: *Aragallus hudsonicus* Greene

= *O. borealis* de Candolle var. *hudsonica* (Greene) Welsh

*Oxytropis hyperborea* Porsild, Sargentia 4: 53. 1943.

Type: N.W.T., Mackenzie R. Delta, E branch, 68°55'N, A. E. Porsild 7033, 21 July 1934; holotype CAN; isotype GH!, S!, US!

= *Oxytropis campestris* (L.) de Candolle var. *carians* (Rydberg) Barneby

*Oxytropis inflata* (Hooker) Steffen, Beih. Bot. Centralbl. 58B: 162. 1938.

Basionym: *O. arctica*  $\delta$  *inflata* Hooker

*O. podocarpa* A. Gray



*Oxytropis involuta* (A. Nelson) K. Schumann, Just's Bot. Jahresb. 27: 496. 1901.

Basionym: *Aragallus involutus* A. Nelson

= *Oxytropis lambertii* Pursh var. *lambertii*

*Oxytropis ixodes* Butters & Abbe, Rhodora 15: 2, tab. 745, figs. 1–6. 1943.

Type: Minnesota, slate cliffs on north side of a high hill 1/2 mi. west of the outlet of South Fowl Lake, Cook County, F. K. Butters, E. C. Abbe, & G. W. Burns 611, 27 June 1940; holotype MIN; isotype CHI, NY!, PH!, US!, UC!, DAO!

= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh var. *ecaudata* Butters & Abbe, Rhodora 45: 4. 1943.

Type: Ontario, slate cliffs east of North Fowl Lake, Thunder Bay District, F. K. Butters, E. C. Abbe, & C. W. Burns 682, 1 July 1940; holotype MIN; isotype GH!

= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh

*Oxytropis johannensis* (Fernald) Fernald, Rhodora 30: 1435, pl. 173. 1928.

Basionym: *O. campestris* (L.) de Candolle var. *johannensis* Fernald

f. *bicensis* Victorin & Rousseau, Cont. Inst. Bot. Univ. Montreal 36: 32. 1940.

Type: Quebec, Rimoufski Co., St. Fabien, Montagne du Bic, J. Rousseau 50297, 15 July 1986; holotype ?; isotype DAO!

= *O. campestris* (L.) de Candolle var. *johannensis* Fernald

*Oxytropis jonesii* Barneby, Proc. Calif. Acad. IV, 27: 215. 1952.

Type: Utah, pink calcareous gravel benches, Red Canyon, Garfield County, alt. 7150 ft., 1947, H. D. Ripley & R. C. Barneby 8550, 7 June 1947; holotype CAS!, isotypes GH!, NY!, RM!

= *O. oreophila* var. *jonesii* (Barneby) Barneby

*Oxytropis jordalii* Porsild, Canad. Field-Nat. 65: 77, tab. 1. 1951.

Type: Alaska, Old John Lake, L. H. Jordal 3580, 1950; holotype CAN; isotypes US!, S!

= *O. campestris* (L.) de Candolle var. *jordalii* (Porsild) Welsh

ssp. *davisii* (Welsh) Elisens & Packer, Canad. J. Bot. 58: 1830. 1980.

Basionym: *O. campestris* (L.) de Candolle var. *davisii* Welsh

= *O. campestris* (L.) de Candolle var. *davisii* Welsh

*Oxytropis kobukensis* Welsh, Iowa State J. Sci. 41: 286. 1967.

Type: Alaska, sand dunes, Kobuk River, across from the mouth of the Hunt River, R. D. Hamilton s.n., 1938; holotype BRY!

Distribution: Sand dunes, Kobuk River, W Alaska; endemic.

The enlarged, purplish stipules on elongate caudex branches are characteristic of this pink-purple flowered plant of dunes in western Alaska. The relationship of this entity likely lies with Siberian species. Jurtsev points to *O. ochotensis* Bunge as having possible relationship. The few specimens of that taxon examined seem to be smaller in all parts and to have chestnut colored stipules

rather than the merely purplish suffused ones of *O. kobukensis*.

*Oxytropis kokrinensis* Porsild, Rhodora 41: 251, tab. 553. 1939.

Type: Kokrines Mountains, north side of divide towards Melozitna River, 65°20'N, 154°30'W, alpine slopes 2000–4000 ft, A. E. & R. T. Porsild 762, 1926; holotype CAN!, fragment S!

Distribution: Ridge tops in the Kokrines Mountains and western Brooks Range, Alaska; endemic.

This species is evidently allied to *O. podocarpa* by its inflated, stipitate pods. It is easily distinguished from that entity by its purplish stipules.

*Oxytropis koyukukensis* Porsild, Canad. Field-Nat. 65: 78. 1951.

Type: Alaska, Wiseman, L. H. Jordal 1763, 15 June 1944; holotype CAN!, isotype US!, ISC!

= *O. arctica* R. Brown var. *koyukukensis* (Porsild) Welsh

*Oxytropis lagopus* Nuttall, J. Acad. Philad. 7: 17. 1834.

Type: Sources of the Missouri, N. B. Wyeth s.n., 1833; holotype PH!, isotype NY!

var. *atropurpurea* (Rydberg) Barneby, Leaff. W. Bot. 5: 111. 1951.

Basionym: *Aragallus atropurpureus* Rydberg, Bull. Torrey Bot. Club 34: 424. 1907.

Distribution: SE Montana, Wyoming, and South Dakota.

var. *conjugans* Barneby, Proc. Calif. Acad. IV, 27: 227. 1952.

Type: Vicinity of Helena, Montana, E. O. Wootton s.n., 1921; holotype US!, isotype NY!

Distribution: W Montana and S Alberta; endemic.

var. *lagopus*

Distribution: N and E Idaho, W Montana, and N Wyoming.

*Oxytropis lambertii* Pursh, Fl. Amer. Sept., 740. 1814.

Type: "On the Missouri, on the bluffs from the Maha village to the Poncars, Louisiana [NE Nebraska or adjacent South Dakota or Iowa], Bradbury s.n., 1811; holotype PH!

β Hooker, Fl. Bor.-Amer. 1: 107. 1834.

Type: *Oxytropis lambertii* β. Dr. Hooker; isotype NY!

= *O. campestris* (L.) de Candolle var. *davisii* Welsh

γ Torrey & Gray, Fl. N. Amer. 1: 339. 1838.

Type: ?

= *O. lambertii* var. *lambertii*

δ ? Torrey & Gray, Fl. N. Amer. 1: 338. 1838.

Type: Quebec, near Quebec, Mrs. Percival s.n.; holotype NY!

= *O. campestris* (L.) de Candolle var. *johannensis* Fernald

var. *articulata* (Greene) Barneby, Leaff. W. Bot. 5: 111. 1951.

Basionym: *Aragallus articulatus* Greene

Distribution: Kansas (Meade Co.), Oklahoma, and Texas.

This plant of the southern prairies and plains is distinguished by its short calyx teeth, large flowers, and shortly exserted or included pods.

- ssp. *bigelovii* (A. Gray) W. A. Weber, *Phytologia* 51: 374. 1982.
- Basionym: *O. lambertii* var. *bigelovii* A. Gray  
= *O. lambertii* var. *bigelovii* A. Gray
- var. *bigelovii* A. Gray, *Proc. Amer. Acad.* 20: 7. 1884.  
Type: Rocky hillsides, upper Canadian [Guadalupe or San Miguel County, New Mexico], J. M. Bigelow s.n., Sept. 21, 1853; holotype GH!; isotype US!  
Distribution: SE Wyoming, Colorado, New Mexico, Arizona, and Utah.
- This plant typically has large flowers and short to elongate calyx teeth and pods. It is mainly a montane or intermontane variety, which abuts with var. *lambertii* in Colorado and Wyoming. Materials of var. *bigelovii* from the canyonlands of Utah and adjacent Arizona have malpighian hairs with very short attachment. Furthermore, the plants tend to be tall, with features of scape, inflorescence, and leaflets attenuated. The leaflets further tend to disarticulate from the rachis readily. Northward from the canyonlands of Kane and San Juan counties, Utah, the attenuation of parts fails, even though the short branch of the malpighian hair persists. There does not seem to be sufficient correlation of morphological features to warrant taxonomic status for these plants that are obviously in transition.
- f. *canadensis* Gandoger, *Bull. Soc. Bot. France* 48: xvi. 1901.  
Type: Southern Manitoba in the valley of the Souris River, Portage-la-Prairie, MacMorine s.n., Aug. 1897; syntype DAO!  
= *O. campestris* (L.) de Candolle var. *gracilis*
- var. *lambertii*  
Distribution: British Columbia, Saskatchewan, Manitoba, Montana, North Dakota, Minnesota, South Dakota, Wyoming, Nebraska, Iowa, Kansas, Missouri, and Wyoming.  
The coincidence of long calyx teeth, small flowers, and elongate pods is diagnostic for this variety of the central and northern prairies and plains.
- var. *lilacina* Cockerell, *W. Amer. Sci.* 5: 11. 1888, nomen.  
= *O. sericea* Nuttall var. *sericea*
- f. *mixta* Gandoger, *Bull. Soc. Bot. France* 48: xvii. 1901  
Type: Minnesota, Montevideo, L. Moyer s.n., 1909; Wyoming, head of Pole Creek, A. Nelson 1320, 27 June 1895; syntypes NY!  
*O. lambertii* var. *lambertii*
- var. *ochroleuca* A. Nelson, *Bull. Wyo. Exper. Sta.* 28: 98. 1896.  
Type: Wyoming, Pole Creek, Albany County, A. Nelson 119, 2 June 1894; holotype RM!; isotype NY!, photo BRY! Nelson named this plant three times, in 1896 as *O. lambertii* var. *ochroleuca*, in 1899 as *Aragallus albiflorus*, and in 1900 as *Aragallus saximontanus*. All are typified on the same collection.  
*O. sericea* Nuttall var. *sericea*
- var. *sericea* (Nuttall) A. Nelson, *Erythra* 7: 62. 1899.  
Basionym: *O. sericea* Nuttall  
= *O. sericea* Nuttall var. *sericea*
- Oxytropis leucantha* (Pallas) Persoon, *Syn.* 2: 331. 1807.  
Basionym: *Astragalus leucanthus* Pallas  
Note: All combinations cited are synonyms of phases of *O. borealis* de Candolle—*O. leucantha* (Pallas) Persoon belongs to *O. campestris* sens. lat., but Jurtsev (1986) regards it as a separate species allied to *O. sordida* (Willdenow) Persoon.
- var. *depressa* (Rydberg) Boivin, *Naturaliste Canad.* 94: 77. 1967.  
Basionym: *Aragallus viscidulus* var. *depressus* Rydberg  
= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh
- var. *hudsonica* f. *galactantha* Boivin, *Naturaliste Canad.* 94: 76. 1967.  
Type: Canada: Franklin District, Melville Peninsula, Repulse Bay, along Nauyas River, P. F. Bruggeman 52, 27 July 1950; holotype DAO!  
= *O. borealis* de Candolle var. *hudsonica* (Greene) Welsh
- var. *gaspensis* (Fernald & Kelsey) Boivin, *Naturaliste Canad.* 94: 76. 1967  
Basionym: *Oxytropis gaspensis* Fernald & Kelsey  
= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh
- var. *hudsonica* (Greene) Boivin, *Naturaliste Canad.* 94: 76. 1967.  
Basionym: *Aragallus hudsonicus* Greene  
= *O. borealis* de Candolle var. *hudsonica* (Greene) Welsh
- var. *ixodes* (Butters & Abbe) Boivin, *Naturaliste Canad.* 94: 76. 1967.  
Basionym: *Oxytropis ixodes* Butters & Abbe  
= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh
- var. *leuchippiana* Boivin, *Naturaliste Canad.* 94: 76. 1967.  
Type: Yukon: Whitehorse, airport area, steep slope, flowers varying in colour from yellow to purple, abundant, J. M. Gillett & J. A. Calder 3181, 4 June 1949; lectotype here selected DAO!; isoelectotype CAS!  
= *O. borealis* de Candolle var. *hudsonica* (Greene) Welsh
- var. *magnifica* Boivin, *Naturaliste Canad.* 94: 77. 1967.  
Type: Alberta, High River, J. Fletcher 457 1/2, 27 June 1902; holotype DAO!  
= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh
- var. *viscida* (Nuttall) Boivin, *Naturaliste Canad.* 94: 77. 1967.  
Basionym: *O. viscida* Nuttall  
= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh
- Oxytropis lunelliana* A. Nelson, *Univ. Wyo. Pub. Bot.* 1: 117. 1926, nom. nov.  
Basionym: *Aragallus collinus* A. Nelson  
*Oxytropis sericea* Nuttall var. *spicata* (Hooker) Barneby
- Oxytropis luteola* (Greene) Piper & Beattie, *Fl. N.-W. Coast*, 334. 1915.  
Basionym: *Aragallus luteolus* Greene  
= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby
- Oxytropis macounii* (Greene) Dayton, *Proc. Biol. Soc. Wash.* 40: 120. 1927.

Basionym: *Aragallus macounii* Greene

= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Oxytropis maydelliana* Trautvetter, Act. Hort. Petrop. 6: 16. 1879.

Type: "... in tractu fluvium Anadyr inter et latus meridionale montium jugi a fluvio hoc septentrionem versus siti" [Chukchi, from the basin of the Anadyr and its northern tributaries], Baron G. von Maydell s.n., 1869; holotype LE?

Distribution: Alaska, Yukon, N British Columbia, N.W.T., E to Hudson Bay and Baffin Island; Chukotsk and Kamchatka.

The yellowish flowers and reddish brown stipules easily characterize this arctic species.

ssp. *melanocephala* (Hooker) Porsild, Nat. Mus. Canada Bull. 216: 47. 1966.

Basionym: *O. campestris* (L.) de Candolle var. *melanocephala* Hooker

= *O. maydelliana* Trautvetter

*Oxytropis mazama* St. John, Proc. Biol. Soc. Wash. 41: 101. 1928.

Type: Washington, Goat Mts., Pierce County, O. D. Allen 245, 6 July, 30 September 1896; holotype WTC; isotype NY!, US!, CAS!, UC!

= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Oxytropis mertensiana* Turczaninow, Bull. Soc. Nat. Mosc., 1840:68. 1840.

Type: "ad sinum Sancti Laurentii," Dr. Mertens; holotype LE.

Distribution: Disjunct in E, N, W Alaska, and N Yukon; arctic Siberia and west to ca 60° E longitude (Jurtsev 1986).

This plant is easily distinguished by its simple primary and trifoliate secondary leaves in conjunction with few-flowered, densely black-villous inflorescences.

*Oxytropis minor* (A. Gray) Cockerell, Torreya 18: 180. 1918.

Basionym: *Oxytropis multiceps* var. *minor* A. Gray

= *O. multiceps* Torrey & Gray

*Oxytropis mollis* Nuttall ex A. Gray, Proc. Amer. Acad. 6: 235. 1864, synonym.

= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh

*Oxytropis monticola* A. Gray, Proc. Amer. Acad. 20: 6. 1884.

Type: Montana, Valley of Jocko River, Lake County, W. M. Canby 91, 18 July 1883; lectotype (Barneby, Proc. Calif. Acad. Sci. IV, 27: 257. 1952) GH!

= *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

This name is lectotypified by Barneby (1952), who selected the type from among a series of specimens cited by Dr. Gray. The syntypes were a mixed lot, with C. C. Parry 87 being a putative hybrid between *O. campestris* var. *gracilis* and *O. borealis* var. *viscida*, Jenney s.n. 1875 belonging to *O. campestris* var. *dispar*, and Lyall s.n. 1862 belonging to *O. campestris* var. *cusickii*. The lectotypification was reviewed by Elisens and Packer (1982).

ssp. *dispar* (A. Nelson) Elisens & Packer, Canad. J. Bot. 58: 1826. 1980.

Basionym: *Aragallus dispar* A. Nelson

*O. campestris* (L.) de Candolle var. *dispar* (A. Nelson) Barneby

*Oxytropis multiceps* Torrey & Gray, Fl. N. Amer. 1: 341. 1838.

Type: "Summit of lofty hills in the Rocky Mountain range, towards Lewis's River [S Wyoming], Rocky Mts.," T. Nuttall s.n., 1834; holotype GH!; isotypes NY!, PH!

Distribution: Colorado, NE Utah, S Wyoming, and W Nebraska.

The accrescent calyces, broad bracts, and few flowers are characteristic for the species, which stands alone in the genus in North America in its morphology.

var. *minor* A. Gray, Proc. Amer. Acad. 20: 2. 1884.

Type: Clear Creek County, Colorado, C. C. Parry 991, 1861; lectotype (here designated by Welsh, cf. Barneby, Proc. Calif. Acad. Sci. IV, 27: 220. 1952) GH!; isotype NY!

= *O. multiceps* Torrey & Gray

*Oxytropis nana* Nuttall ex Torrey & Gray, Fl. N. Amer. 1: 340. 1838.

Type: Plains of the Platte in the Rocky Mountain Range [Wyoming], T. Nuttall s.n. 1834; holotype PH!; isotype NY!

Distribution: Drainage of the North Platte and Cheyenne rivers, westward to the Wind River Mountains, Albany, Carbon, Converse, Fremont, Natrona, Platte, and Sweetwater counties, Wyoming; endemic.

This is a beautiful species of clays, shales, and gravelly bluffs and ridge tops endemic to Wyoming. Barneby (1952) postulated that it might have arisen through hybridization of *O. sericea* and *O. multiceps*, a very likely supposition. Flower colors are variable in a given population from pale pinks through lavender and purple, and white-flowered populations are known. A contribution from *O. lambertii* is also suggested by the presence of incipiently malpighian hairs in some specimens. The relationship to segregates of *O. besseyi* seems tenuous at best. The relegation of *O. nana* to that species might require a realignment of other taxa as well, including combination of *lambertii*, *sericea*, *campestris*, and even *multiceps*. Such a proposal is, of course, absurd. Taxonomy must be both practical and reflect biological reality.

var. *argophylla* (Rydberg) Isely, Syst. Bot. 8: 425. 1983.

Basionym: *Aragallus argophyllus* Rydberg

= *O. besseyi* (Rydberg) Blankinship var. *argophylla* (Rydberg) Isely

var. *besseyi* (Rydberg) Isely, Syst. Bot. 8: 425. 1983.

Basionym: *Aragallus besseyi* Rydberg

= *O. besseyi* (Rydberg) Blankinship var. *besseyi*

var. *fallax* (Barneby) Isely, Syst. Bot. 8: 425. 1983.

Basionym: *O. besseyi* (Rydberg) Blankinship var. *fallax* Barneby

var. *obnapiformis* (C. L. Porter) Isely, Syst. Bot. 8: 425. 1983.

Basionym: *O. obnapiformis* C. L. Porter

- var. *salmonensis* (Barneby) Isely, Syst. Bot. 8: 425. 1983.  
 Basionym: *O. besseyi* (Rydberg) Blankinship var. *salmonensis* Barneby
- var. *ventosa* (Greene) Isely, Syst. Bot. 8: 425. 1983.  
 Basionym: *Aragallus ventosa* Greene
- Oxytropis nigrescens* (Pallas) Fischer ex de Candolle, Prodr. 2: 278. 1825.
- ssp. *arctobia* (Bunge) Hulten, Ark. Bot. (n.s.) 7: 80. 1968.  
 Basionym: *O. arctobia* Bunge  
 = *O. nigrescens* (Pallas) Fischer var. *uniflora* (Hooker) Barneby
- var. *arctobia* (Bunge) A. Gray, Proc. Amer. Acad. 20: 3. 1884  
 Basionym: *O. arctobia* Bunge  
 = *O. nigrescens* (Pallas) Fischer var. *uniflora* (Hooker) Barneby
- ssp. *bryophila* (Greene) Hulten, Fl. Alaska & Yukon, 1102, map 833. 1947.  
 Basionym: *Aragallus bryophilus* Greene, Proc. Biol. Soc. Wash. 18: 17. 1905.  
 = *O. nigrescens* (Pallas) Fischer var. *nigrescens*
- var. *bryophila* (Greene) Lepage, Amer. Midl. Nat. 46: 758. 1952  
 Basionym: *Aragallus bryophilus* Greene  
 = *O. nigrescens* (Pallas) Fischer var. *nigrescens*
- var. *bryophila* f. *albida* Lepage, Amer. Midl. Nat. 46: 758. 1952.  
 Type: Alaska, Kodiak, Old Woman Mt., Lepage 25059, 24 June 1949; holotype ?; isotype DAO!, RIM!, fragment BRY!  
 = *O. nigrescens* (Pallas) Fischer var. *nigrescens*
- var. *genuina* Kjellman, Vega-Exped. Vetensk. Arb., 16. 1883, nomen.  
 = *O. nigrescens* (Pallas) Fischer var. *nigrescens*
- var. *lonchopoda* Barneby, Leaf. W. Bot. 10: 23. 1963.  
 Type: Yukon, Cathedral Rocks, Ogilvie Range, J. A. Calder & J. M. Gillett 26013A, 29 June 1960; holotype DAO!; isotype NY!  
 Distribution: Ogilvie Mts., Yukon; endemic.  
 The variety rests almost solely upon the pods being definitely stipitate. There is considerable variation in stipe length through the range of *O. nigrescens* apart from the phase segregated as var. *lonchopoda*. The localization of an elongated stipe in plants from the Ogilvie Mts. might prove ultimately to represent a mere continuum and lack value in designation of a taxon. Plants from there in vegetative condition are essentially like those of phases of *O. nigrescens* from elsewhere. The elongate stipe and slightly inflated pods are reminiscent of *O. podocarpa*, but the leaflets are as var. *nigrescens*.
- var. *nigrescens*  
 Distribution: a Hibernian, coastal Yukon to Bering Strait, south to Kodiak, and in interior Yukon and Alaska, N.W.T. (Mackenzie Mts.), and British Columbia; Siberia and Kamchatka.  
 This is a highly variable taxon with green and silvery, loose and compact, villous to strigose or even glabrous plants growing intermingled. And, it is with the often mixed variants that infraspecific segregation has been attempted. The synonymy is long, indicating the diversity of form but not necessarily the presence of several taxa within the complex morphology of the species.
- ssp. *pygmaea* (Pallas) Hulten, Fl. Alaska & Yukon, 1102. 1947  
 Basionym: *Astragalus pygmaeus* Pallas  
 = *O. nigrescens* (Pallas) Fischer var. *nigrescens*
- var. *pygmaea* (Pallas) Chamisso, Linnaea 6: 546. 1831.  
 Basionym: *Astragalus pygmaeus* Pallas  
 = *O. nigrescens* (Pallas) Fischer var. *nigrescens*
- var. *uniflora* (Hooker) Barneby, Proc. Calif. Acad. IV, 27: 209. 1952.  
 Basionym: *O. arctica*  $\beta$  *uniflora* Hooker  
 Distribution: Islands of the Canadian Arctic Archipelago and along the arctic coast from Mackenzie Delta E to Baffin Island and Hudson Bay, less commonly in interior sites in Yukon.
- This plant, as interpreted by me, is an American (more precisely a Canadian) endemic, but there are plants from the Chukotsk that match them closely (see *O. gorodkovii* Jurtsev, a new name for *O. pygmaea*, a phase of var. *nigrescens*). The Siberian materials seem to represent mere ecological variants within an expanded var. *nigrescens*, however.
- Oxytropis obnapiformis* C. L. Porter, Madrono 9: 133, fig. 1947.  
 Type: Colorado, in the sand hills 8–9 mi W of Maybell, Moffat County, 5,900 ft., C. L. Porter 3864, 19 June 1946; holotype RM!; isotypes GH!, RSA, US!  
 = *O. besseyi* (Rydberg) Blankinship var. *obnapiformis* (C. L. Porter) Welsh
- Oxytropis okanoganea* St. John, Proc. Biol. Soc. Wash. 41: 102. 1925.  
 Type: Washington, n.w. of Riverside, Okanogan County, H. St. John 7728; holotype WTC.  
 = *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby
- Oxytropis olympica* St. John, Proc. Biol. Soc. Wash. 41: 103. 1925.  
 Type: Washington, Olympic Mts., Jefferson County, B. Flett 134, 24 July 1897; holotype WTC; isotype US!; photo BRY!  
 = *O. campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby
- Oxytropis oreophila* A. Gray, Proc. Amer. Acad. 20: 3. 1884.  
 Type: Utah, Aquarius Plateau, 10,500 ft., Garfield County, L. F. Ward 541, 9 August 1875; lectotype (here designated by Welsh, cf. Barneby, Proc. Calif. Acad. Sci. IV, 27: 214. 1952) GH!, isoelectotype NY!
- var. *jonesii* (Barneby) Barneby, Intermountain Fl. 3B: 183. 1989.  
 Basionym: *O. jonesii* Barneby  
 Distribution: Uinta Basin, Wasatch Plateau, and Paunsaugunt and Markagunt plateaus, Utah; endemic.

This is a caespitose, mat- or mound-forming plant, of moderate elevations in mountain brush or ponderosa pine zones. Its compact growth, large flowers, and short peduncles are characteristic for the variety. It is more or less transitional with the next variety.

var. *juniperina* Welsh, Great Basin Nat. 38: 339. 1978.

Type: Utah, ca 1 mi E of Bicknell, Wayne County, S. L. Welsh & G. Moore 13828, 1976; holotype BRY!; isotype NY!

Distribution: Nevada and Utah; endemic.

This is a caespitose, mat- or mound-forming plant, of low-elevation, xeric sites. The compact growth, smallish flowers, and short peduncles are characteristic for the variety.

var. *oreophila*

Distribution: Arizona, California, Nevada, and Utah.

This is the taller, more robust phase of the species with elongate scapes bearing clustered, bladdery-inflated pods, more typical of high elevations where it often grows intermingled with *O. parryi*.

*Oxytropis parryi* A. Gray, Proc. Amer. Acad. 20: 4. 1884.

Type: "Rocky Mountains of northern New Mexico and Colorado, near the limit of trees" [Sangre de Cristo Pass, Taos Co., N.M.], C. C. Parry 41, 1867; lectotype (here designated by Welsh, cf. Barneby, Proc. Calif. Acad. Sci. IV, 27: 218. 1952) GH! Rocky Mountains, E. Hall & H. Harbour; cotypes GH!, NY!

Distribution: Montana (?), Idaho, Wyoming, California, Nevada, Utah, Colorado, and New Mexico.

*Oxytropis patens* (Rydberg) A. Nelson, Univ. Wyo. Pub. Bot. 1: 114. 1926.

Basionym: *Aragallus patens* Rydberg

= *Oxytropis lambertii* Pursh var. *bigelovii* A. Gray

*Oxytropis paysoniana* A. Nelson, Univ. Wyo. Pub. Bot. 1: 119. 1926.

Type: Wyoming, Piney Mt., 25 miles west of Big Piney, Sublette County, E. & L. Payson 2700, July 12, 1922; holotype RM!; isotypes NY!, US!

= *O. campestris* (L.) de Candolle var. *cusickii* (Greenman) Barneby

*Oxytropis pinetorum* (A. Heller) K. Schumann, Just's Bot. Jahresb. 27: 496. 1901.

Basionym: *Aragallus pinetorum* A. Heller

= *O. sericea* Nuttall var. *sericea*

*Oxytropis plattensis* Nuttall ex Torrey & Gray, Fl. N. Amer. 1: 340. 1838.

Type: Platte Plains, Nuttall s.n.; isotype NY!

= *O. lambertii* var. *lambertii*

*Oxytropis podocarpa* A. Gray, Proc. Amer. Acad. 6: 234. 1864.

Type: Labrador (Schweinitz) and Alberta (Bourgeau); cotypes GH! The specimens are cotypical, both having been used by Gray in characterization of the species.

Distribution: Rocky alpine ridges and coastal shores, in Colorado, Wyoming, Montana, Alberta, N.W.T., Ungava Peninsula, Labrador, and Baffin Island.

The bladdery-inflated stipitate pods are characteristic of this and few other species of oxytropes. The

folded, falcate leaflets are useful in distinguishing this from closely related mat- or mound-forming species, such as *O. nigrescens*, in vegetative condition.

var. *inflata* (Hooker) Boivin, Naturaliste Canad. 94: 78. 1967.

Basionym: *O. arctica*  $\delta$  *inflata* Hooker

= *O. podocarpa* A. Gray

*Oxytropis pygmaea* (Pallas) Fernald, Rhodora 30: 153. 1928.

Basionym: *Astragalus pygmaeus* Pallas

= *Oxytropis nigrescens* (Pallas) Fischer var. *nigrescens*

*Oxytropis retrorsa* Fernald, Rhodora 30: 140. 1928.

Type: Colorado, vicinity of Como [Park Co.], South Park, C. S. Crandall & J. S. Cowen 152, August 3, 1895; holotype GH!; isotype NY!

= *O. deflexa* var. *sericea* Torr. & Gray

var. *sericea* (Torrey & Gray) Fernald, Rhodora 30: 140. 1928.

*O. retrorsa* ssp. *sericea* (Torrey & Gray) Love & Love, Taxon 31: 347. 1982.

= *O. deflexa* var. *sericea* Torrey & Gray

*Oxytropis richardsonii* (Hooker) K. Schumann, Just's Bot. Jahresb. 27: 496. 1901.

Basionym: *O. splendens*  $\beta$  *richardsonii* Hooker

= *O. splendens* Douglas

*Oxytropis riparia* Litvinov, Sched. Herb. Fl. Ross. 6: 98. 1908.

Type: Russian Turkestan, from Farab (on the Amu Darya); holotype LE.

Distribution: Idaho, Montana, North Dakota, and Wyoming; introduced from central Asia.

This is a coarse perennial herb with the general aspect of *O. deflexa* (Pallas) de Candolle. It grows in riparian habitats where it is grazed by wildlife, especially by sage hens. The species is expected to spread in suitable habitats through much of the American West.

*Oxytropis roaldii* Ostenfeld, Vasc. Pl. Arctic N. Amer. Gjoa Exped., 54, pl. 3, fig. 16. 1910.

Type: Iter arcticus Roald Amundsen (Gjoa-Expedition) 1903–1906. America Arct., Herschell Island, Lat N 69°35' Long. W 138°50', 13 July 1906. A. H. Lindstrom s.n.; isotype NY!

= *O. campestris* (L.) de Candolle var. *roaldii* (Ostenfeld) Welsh

*Oxytropis rydbergii* A. Nelson, Univ. Wyo. Pub. Bot. 1: 117. 1926.

nom. nov. pro *Aragallus alpicola* Rydberg

= *O. campestris* (L.) de Candolle var. *cusickii* (Greenman) Barneby

*Oxytropis saximontana* (A. Nelson) A. Nelson, Univ. Wyo. Pub. Bot. 1: 113. 1926.

Basionym: *Aragallus saximontanus* A. Nelson, nom. nov. *Oxytropis lambertii* Pursh var. *ochroleuca* A. Nelson

= *Oxytropis sericea* Nuttall var. *sericea*

*Oxytropis scammaniana* Hulten, Ark. Bot. 33B: 4, figs. 2, 3 (map). 1947.

Type: Alaska, Eagle Summit, near Steese Highway 109 miles north of Fairbanks, elevation 3850 feet,

E. Scamman 806, 7–11 July 1937; holotype S!; isotype GH!; photo BRY!

Distribution: Alaska, Yukon, and N.W.T. (Mackenzie Mts.); endemic.

This plant is similar to *O. mertensiana*, possibly its nearest ally in North America, in both inflorescence and pod aspect and structure.

*Oxytropis sericea* Nuttall ex Torrey & Gray, Fl. N. Amer. 1: 39. 1835.

Type: Rocky Mountains towards the sources of the Oregon [S Wyoming], T. Nuttall s.n., 1834; holotype NY!

var. *sericea*

Distribution: Montana, Wyoming, South Dakota, Nebraska, Idaho, Oregon, Nevada, Utah, Colorado, Kansas, New Mexico, and Oklahoma.

This variety forms hybrids with *O. lambertii* at points where the two entities come in contact. Especially impressive hybrid populations occur along the western Great Plains and in the Rocky Mountain foothills. The great swarms of hybrids, back crosses, and derivatives at Nederland, Colorado, are especially distinctive, with floral colors and sizes not readily evident in either of the parental types. There are indications, also, of transitional material between this variety and phases of *O. besseyi*.

var. *spicata* (Hooker) Barneby, Leaflet. W. Bot. 5: 111. 1951.

Basionym: *O. campestris* (L.) de Candolle  $\delta$  *spicata* Hooker

Distribution: Yukon, British Columbia, Alberta, Saskatchewan, Manitoba, Montana, Idaho, and Wyoming.

Members of this variety are characterized by their ochroleucous flowers with immaculate keels. In general aspect they simulate the partially sympatric *O. campestris* var. *gracilis*, from which they may be distinguished on the basis of the smaller number of leaflets and generally larger flowers. Alpine phases of *O. campestris* var. *cusickii* approach both flower size and color of var. *sericea*. Mainly var. *sericea* is not a plant of the highlands where that variety grows, but the similarities should not be discounted. Apparent hybrids are known between this and *O. campestris* var. *davisii* in northeastern British Columbia.

*Oxytropis sheldonensis* Porsild, Bull. Nat. Mus. Canad. 121: 246. 1951.

Type: Yukon, Canol Rd.: South and east slopes of Mt. Sheldon, steep ravines and ledges opposite mile 222, A. E. Porsild & A. J. Breitung 11750, 11 August 1944; holotype CAN!; isotypes GH!, ISC!, US!, NY!, UC!

— *O. borealis* de Candolle var. *sulphurea* (Porsild) Welsh

*Oxytropis sordida* (Willdenow) Persoon, Syn. Pl. 2: 332. 1807.

Basionym: *Astragalus sordidus* Willdenow

ssp. *barnebyana* (Welsh) Jurtsev, Arctic Fl. U.S.S.R. 9(2): 109. 1986.

Basionym: *O. arctica* R. Brown var. *barnebyana* Welsh

— *O. arctica* R. Brown var. *barnebyana* Welsh

ssp. *murrayi* Jurtsev, Arctic Fl. U.S.S.R. 9(2): 179. 1986.

Type: Yukon, St. Elias Mts., Observation Mt. and vicinity, at terminus of Kaskawulsh Glacier, D. F. & B. M. Murray 522, 1966; holotype LE!; isotype ALA, BRY!

— *O. arctica* R. Brown var. *murrayi* (Jurtsev) Welsh

*Oxytropis spicata* (Hooker) Standley, Contr. U. S. Nat. Herb. 22: 373. 1921.

Basionym: *O. campestris*  $\delta$  *spicata* Hooker

— *O. sericea* Nuttall var. *spicata* (Hooker) Barneby

*Oxytropis splendens* Douglas ex Hooker, Fl. Bor.-Amer. 1: 147. 1834.

Type: Canada, on limestone rocks of the Red River, and south toward Pembina [S Manitoba], D. Douglas s.n.; holotype ?; isotype OXF!, photo BRY!

Distribution: E. Alaska, Yukon, N.W.T., Ontario, Manitoba, Saskatchewan, Alberta, British Columbia, Montana, North Dakota, Minnesota, Wyoming, Colorado, and New Mexico.

This species is, for the most part, readily identifiable by its copious vestiture, fasciculate leaflets, and short corollas relative to calyx length. In the Alberta Rockies there occur apparent intermediates with portions of *O. campestris* var. *gracilis*. Inconclusive specimens are known between *O. splendens* and both *O. campestris* var. *johannensis* near James Bay and var. *davisii* in British Columbia and Alberta. The intermediate specimens have less copious pubescence, a tendency to fasciculate leaflets, and petal to calyx proportions intermediate from those typical of *splendens* to those typical of the *campestris* taxa.

f. *nelsonii* Gandoger, Bull. Soc. Bot. France 48: xvii. 1901.

Type: ?

— *O. splendens* Douglas

$\beta$  *richardsonii* Hooker, Fl. Bor.-Amer. 1: 148. 1834.

Type: Richardson. "Franklin's Journey, Dr. Hooker"; isotype NY!, *O. oxyphylla* of Richardson, isotype GH!

— *O. splendens* Douglas

f. *strigosa* Gandoger, Bull. Soc. Bot. France 48: xvii. 1901.

Type: ?

— *O. splendens* Douglas

$\alpha$  *vestita* Hooker, Fl. Bor.-Amer. 1: 148. 1834

Type: Red River, D. Douglas; holotype ?

— *O. splendens* Douglas

*Oxytropis terrae-novae* Fernald, Rhodora 30: 147, pl. 174. 1928.

Type: Newfoundland, St. John Island, peat on dry gravelly limestone barrens, M. L. Fernald et al. 28615, 31 July 1925; holotype GH!

— *O. campestris* (L.) de Candolle var. *terrae-novae* (Fernald) Barneby

*Oxytropis tschuktschorum* Jurtsev, Bot. Journ. 53: 11. 1938. 1968.

— *O. nigrescens* (Pallas) Fischer var. *nigrescens*

*Oxytropis uralensis*  $\delta$  *arctica* (R. Brown) Ledebour, Fl. Ross. 1: 594. 1842.

Basionym: *Oxytropis arctica* R. Brown

*O. arctica* R. Brown var. *arctica*

*γ minor* Hooker, Fl. Bor.-Amer. 1: 146. 1834.

Note: Barneby cites this name as problematical, to be excluded because of inadequate typification. The Labrador specimens cited with the original description are likely what now passes under *O. campestris* var. *terrae-notae*; the remainder is cited from dry hills and prairies in the Rock Mountains, and remains obscure.

β *subsucculenta* Hooker, Fl. Bor.-Amer. 1: 146. 1831.

Type: "Arctic seashore, to the east of the Mackenzie River," Dr. Richardson s.n.; holotype K.

= *O. borealis* de Candolle var. *borealis*

*Oxytropis varians* (Rydberg) K. Schumann, Just's Bot. Jahrb. 29: 543. 1903.

Basionym: *Aragallus varians* Rydberg

= *O. campestris* (L.) de Candolle var. *varians* (Rydberg) Barneby

*Oxytropis vegana* (Cockerell) Wooton & Standley, Contr. U. S. Nat. Herb. 16: 136. 1913.

Basionym: *Aragallus pinctorum veganus* Cockerell  
= *O. sericea* Nuttall var. *sericea*

*Oxytropis verruculosa* Porsild, Bull. Nat. Mus. Canad. 121: 246. 1951.

Type: Yukon: Canol Rd.: Rose-Lapic Pass, southwest of granite mountain west of mile 116, alpine slopes from road to below summit. Elev. 5000 ft. rocky ledges. A. E. Porsild & A. J. Breitung 10072, 1 July 1944; holotype CAN!; isotype GH!, S!, US!  
= *O. borealis* de Candolle var. *sulphurea* (Porsild) Welsh

*Oxytropis villosa* (Rydberg) K. Schumann, Just's Bot. Jahrb. 29: 543. 1903.

Basionym: *Aragallus villosus* Rydberg

= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Oxytropis viscida* Nuttall ex Torrey & Gray, Flora N. Amer. 1: 341. 1838.

Type: Rocky Mountains, near the sources of the Oregon [SW Wyoming], T. Nuttall s.n., 1834; syntypes NY!, PH; and "R. Mts. Oxytropis mollis," GH!

= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh var. *hudsonica* (Greene) Barneby, Proc. Calif. Acad. IV, 27: 245. 1952.

Basionym: *Aragallus hudsonicus* Greene

ssp. *hudsonica* (Greene) Love & Love, Taxon 31: 347. 1952.

Basionym: *Aragallus hudsonicus* Greene

var. *subsucculenta* (Hooker) Barneby, Proc. Calif. Acad. IV, 27: 246. 1952.

Basionym: *Oxytropis uralensis* β *subsucculenta* Hooker

var. *viscida*

*Oxytropis viscidula* (Rydberg) Tidestrom, Contr. U. S. Nat. Herb. 25: 332. 1925.

Basionym: *Aragallus viscidulus* Rydberg

= *O. borealis* de Candolle var. *viscida* (Nuttall) Welsh

ssp. *sulphurea* Porsild, Bull. Nat. Mus. Canad. 121: 247. 1951.

Type: Yukon: Canol Rd.: Rose-Lapic R. Pass, mile 105; schist mountain east of lake. Elev. 4000, shaly cliffs by waterfall. A. E. Porsild & A. J. Breitung 10918, July 19, 1944; holotype CAN; isotype ISC!, GH!, S!, US!, NY!

*O. borealis* de Candolle var. *sulphurea* (Porsild) Welsh

*Physocalyx multiceps* Nuttall ex Gray, Proc. Amer. Acad. 6: 234. 1864.

Type: Rocky Mountains, T. Nuttall s.n., 1834; holotype PH!; isotype NY!

*Oxytropis multiceps* Torrey & Gray

*Spiesia arctica* (R. Brown) Kuntze, Rev. Gen. 205. 1891.

Basionym: *Oxytropis arctica* R. Brown var. *arctica*

= *Oxytropis arctica* R. Brown var. *arctica*

*Spiesia arctobia* (Bunge) Kuntze, Rev. Gen. 205. 1891.

Basionym: *Oxytropis arctobia* Bunge

= *O. nigrescens* (Pallas) Fischer var. *uniflora* (Hooker) Barneby

*Spiesia bellii* Britton ex Macoun, Can. Rec. Sc. 6: 148. 1894.

Type: Canada, Digges Island, R. Bell s.n., 15 Sept. 1884; holotype CAN!; isotype NY!, US!

= *Oxytropis arctica* R. Brown var. *bellii* (Britton) Boivin

*Spiesia inflata* (Hooker) Britton, Mem. Torrey Bot. Club 5: 201. 1894.

Basionym: *Oxytropis arctica* δ *inflata* Hooker

= *O. podocarpa* A. Gray

*Spiesia lagopus* (Nuttall) Kuntze, Rev. Gen., 206. 1891.

Basionym: *Oxytropis lagopus* Nuttall

= *Oxytropis lagopus* Nuttall

*Spiesia lambertii* (Pursh) Kuntze, Rev. Gen., 206. 1891.

Basionym: *Oxytropis lambertii* Pursh

= *Oxytropis lambertii* Pursh var. *lambertii*

var. *sericea* (Nuttall) Rydberg, Fl. Neb. 21: 43, pl. XI, figs. 107–109. 1895.

Basionym: *Oxytropis sericea* Nuttall

= *Oxytropis sericea* Nuttall

*Spiesia mertensiana* (Turczaninow) Kuntze, Rev. Gen., 206. 1891.

Basionym: *Oxytropis mertensiana* Turczaninow

= *Oxytropis mertensiana* Turczaninow

*Spiesia monticola* (A. Gray) Kuntze, Rev. Gen., 206. 1891.

Basionym: *Oxytropis monticola* A. Gray

= *Oxytropis campestris* (L.) de Candolle var. *gracilis* (A. Nelson) Barneby

*Spiesia multiceps* (Torrey & Gray) Kuntze, Rev. Gen., 206. 1891.

Basionym: *Oxytropis multiceps* Torrey & Gray

= *Oxytropis multiceps* Torrey & Gray

*Spiesia nana* (Nuttall) Kuntze, Rev. Gen., 206. 1891.

Basionym: *Oxytropis nana* Nuttall

= *Oxytropis nana* Nuttall

*Spiesia nigrescens* (Pallas) Kuntze, Rev. Gen., 206. 1891.

Basionym: *Astragalus nigrescens* Pallas

= *Oxytropis nigrescens* (Pallas) Fischer var. *nigrescens*

- Spiesia oreophila* (A. Gray) Kuntze, Rev. Gen., 206. 1891.  
 Basionym: *Oxytropis oreophila* A. Gray  
 = *Oxytropis oreophila* A. Gray
- Spiesia parryi* (A. Gray) Kuntze, Rev. Gen., 206. 1891.  
 Basionym: *Oxytropis parryi* A. Gray  
 = *Oxytropis parryi* A. Gray
- Spiesia podocarpa* (A. Gray) Kuntze, Rev. Gen., 206. 1891.  
 Basionym: *Oxytropis podocarpa* A. Gray  
 = *Oxytropis podocarpa* A. Gray
- Spiesia splendens* (Douglas) Kuntze, Rev. Gen., 207. 1891.  
 Basionym: *Oxytropis splendens* Douglas  
 = *Oxytropis splendens* Douglas
- Spiesia viscida* (Nuttall) Kuntze, Rev. Gen., 206. 1891.  
 Basionym: *Oxytropis viscida* Nuttall  
 = *Oxytropis borealis* de Candolle var. *viscida* (Nuttall) Welsh
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- . 1987. *Oxytropis* DC. Pages 396-398 in S. L. Welsh, N. D. Atwood, S. Goodrich, and L. C. Higgins, A Utah flora. Great Basin Naturalist Memoirs 9. 984 pp.

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# ALKALOIDAL RELATIONSHIPS IN THE GENUS *ARCTOMECON* (PAPAVERACEAE) AND HERBIVORY IN *A. HUMILIS*

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**ABSTRACT**—The previously reported alkaloids (including protopines, benzophenanthridines, tetrahydrobenzylisoquinolines, and protoberberines) of the genus *Arctomecon* (Papaveraceae) are discussed in relation to their distribution in the plant kingdom, in the Papaveraceae, and among the three species of *Arctomecon*. The biological activity of these alkaloids is discussed, and possible implications for herbivore and plant-insect interactions in *A. humilis* are presented.

**Key words:** *Arctomecon*, *Papaveraceae*, alkaloids, herbivory.

The Papaveraceae genus *Arctomecon* contains only three species, all rare endemics in the western United States. The geographic distribution of the bear or desert poppies, *Arctomecon* spp., is shown in Figure 1. The great bear poppy (*A. merriamii* Coville) is the most common of these species, extending from the Las Vegas area of southern Nevada to the Death Valley region of southeastern California. *A. californica* Torr. & Fremont, the yellow bear poppy, was once common in the vicinity of Las Vegas and the Lake Mead region of southern Nevada and northwestern Arizona, but numbers have rapidly declined due to habitat loss. The dwarf bearclaw poppy (*A. humilis* Coville) is disjunct from the other species, growing exclusively in Washington County, Utah. *A. humilis* has been declared an endangered species by the U.S. Fish and Wildlife Service under the Endangered Species Act of 1973 as amended, while both *A. merriamii* and *A. californica* are presently under consideration for such protection. Habitat requirements and ecological relations of *A. humilis* and *A. californica* have been studied by Meyer (1986, 1989) and Nelson (1989). Both are obligate gypsophiles. Unlike the other two species, *A. merriamii* is not restricted to gypsum-rich soils but often occurs on shallow soils derived from limestone.

We have reported elsewhere (Raynie et al. 1990) the alkaloid chemicals found in this genus. Sixteen different isoquinoline alkaloids from four classes were found, and the structural details (for 14 of those alkaloids)

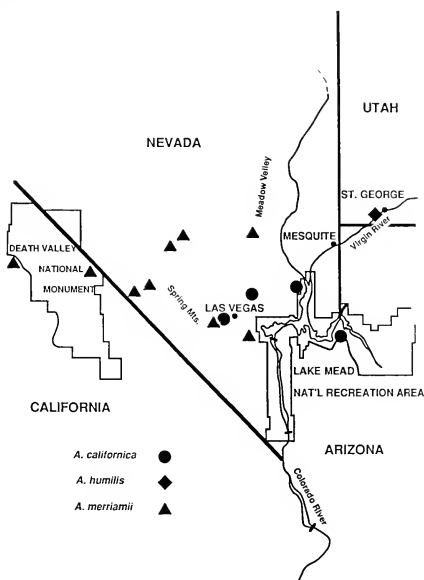
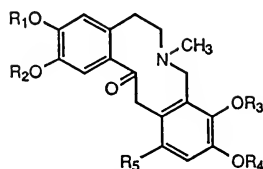


Fig. 1. Distribution of *Arctomecon* (Papaveraceae).

were determined. The structures of the alkaloids known for these species are shown in Figure 2. The alkaloids identified include the protopines allocryptopine, protopine, cryptopine, and 12-methoxyallocryptopine; the benzophenanthridines chelerythrine,

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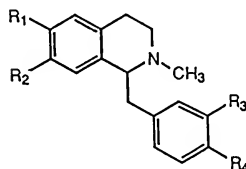
PROTOPINES

Allocryptopine:  $R_1-R_2 = CH_2$   $R_3 = R_4 = CH_3$   $R_5 = H$

Protopine:  $R_1-R_2$  and  $R_3-R_4 = CH_2$   $R_5 = H$

Cryptopine:  $R_1 = R_2 = CH_3$   $R_3-R_4 = CH_2$   $R_5 = H$

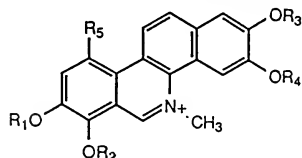
12-Methoxyallocryptopine:  $R_1-R_2 = CH_2$   $R_3 = R_4 = CH_3$   $R_5 = OCH_3$

TETRAHYDROBENZYLISOQUINOLINES

Reticuline:  $R_1 = R_4 = OCH_3$   $R_2 = R_3 = OH$

Pseudolaudanine:  $R_1 = OH$   $R_2 = R_3 = R_4 = OCH_3$

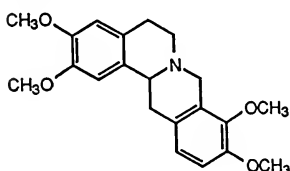
Arnepavine:  $R_1 = R_2 = OCH_3$   $R_3 = H$   $R_4 = OH$

BENZOPHENANTHRIDINES

Chelerythrine:  $R_1 = R_2 = CH_3$   $R_3-R_4 = CH_2$   $R_5 = H$

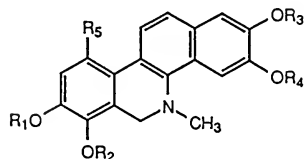
Sanguinarine:  $R_1-R_2$  and  $R_3-R_4 = CH_2$   $R_5 = H$

Sanguirubine:  $R_1-R_2 = CH_2$   $R_3 = R_4 = CH_3$   $R_5 = OCH_3$

PROTOBERBERINES

Tetrahydropalmatine  
N-Methyltetrahydropalmatine

Fig. 2 continued.



Dihydrochelerythrine  
Dihydrosanguinarine

Fig. 2. Structures of alkaloids found in *Arctomecon* (Papaveraceae).

sanguinarine, sanguirubine, dihydrochelerythrine, and dihydrosanguinarine; the tetrahydrobenzylisoquinolines arnepavine, pseudolaudanine, and reticuline; and the protoberberines tetrahydropalmatine and N-methyltetrahydropalmatine. One of these, 12-methoxyallocryptopine, was reported for the first time in our earlier study (Raynie et al. 1990). In this contribution, the alkaloids of *Arctomecon* are compared with the alkaloids of other genera of Papaveraceae. The possible

values of these alkaloids to the species that produce them are also discussed.

#### DISTRIBUTION AND PHYSIOLOGICAL ACTIVITY OF *ARCTOMECON* ALKALOIDS

The presence of alkaloids (i.e., the ability to synthesize or accumulate alkaloids) occurs in many lineages within the plant kingdom, especially among the dicotyledons. A brief summary of the distribution in the plant kingdom of the alkaloid types reported in *Arctomecon* and their known physiological activity follows.

Cordell (1981) reviewed the phylogenetic distribution and pharmacological activity of alkaloids. In addition to the Papaveraceae, the protopines are found in four plant families (Berberidaceae, Fumariaceae, Ranunculaceae, and Rutaceae) and are represented by about 20 compounds. The physiological effects of the protopines on mammals include active dilation of coronary vessels and local anesthetic effects (Preininger 1975). The benzophenanthridines are limited to the

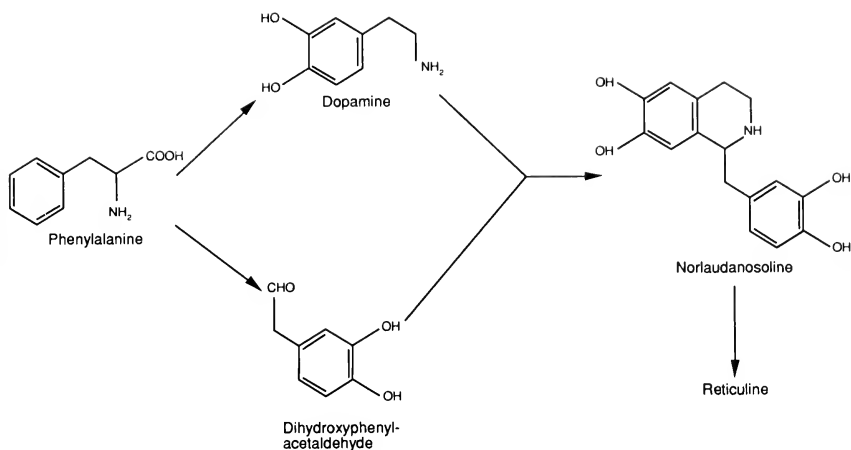


Fig. 3. Initial steps in biosynthetic scheme of Papaveraceae alkaloids from phenylalanine (after Preininger 1986).

Papaveraceae, Fumariaceae, and Rutaceae. Chelerythrine and sanguinarine, representative benzophenanthridines found in *Arctomecon*, are reported to have cytotoxic, antifungal, antiprotozoal, antibacterial, and potential anticancer activity (Cordell 1981). The tetrahydrobenzylisoquinolines, especially reticuline, are best known as biosynthetic intermediates for many other alkaloids. The protoberberines are among the most widely distributed of the isoquinoline alkaloids, occurring in nine plant families, including Annonaceae, Berberidaceae, Fumariaceae, Lauraceae, Menispermaceae, Papaveraceae, and Rutaceae. Over 40 protoberberines are known. They display at least three types of biological activity; antimicrobial, stimulation of uterine contractions, and antileukemic and antineoplastic.

#### RELATIONSHIP OF *ARCTOMECON* ALKALOIDS IN THE PAPAVERACEAE

The Fumariaceae and Papaveraceae are closely related families in the order Papaverales. According to Cronquist (1981), the poppy family, Papaveraceae, contains 25 genera and about 200 species. This family is unusual in that all of its species are reported to contain alkaloids (Pelletier 1970). A major feature of both the Fumariaceae and the

Papaveraceae is the presence of alkaloids derived from tetrahydroisoquinolines (Preininger 1986). Preininger (1986) has reviewed, by genus, the alkaloids of the Papaveraceae and demonstrated how the biodiversity of the poppy family is reflected in its chemical diversity. The isoquinoline alkaloids can be biosynthesized from the amino acid phenylalanine by the condensation of dopamine with 3,4-dihydroxyphenylacetaldehyde followed by the Mannich condensation, yielding norlaudanosoline. From norlaudanosoline, intermediates such as reticuline and orientaline are formed in the biosynthesis of a variety of isoquinoline types (Preininger 1986). This biosynthetic scheme is shown in Figure 3.

According to Preininger's review (1986), protoberberines, benzophenanthridines, and protopines are the most widespread alkaloids in the Papaveraceae, present in almost all genera. Quaternary tetrahydroprotoberberines serve as intermediates in the biosynthetic processes that produce the foregoing alkaloids. Consequently these alkaloids were considered as a chemotaxonomically significant characteristic of the Papaveraceae. As discussed earlier, alkaloids from each of these classes, as well as tetrahydrobenzylisoquinoline alkaloids, occur in *Arctomecon*. Table 1 shows the distribution of the alkaloids found in *Arctomecon* among other Papaveraceae

TABLE 1. Distribution of alkaloids known to occur in *Arctomecon* among other genera of the Papaveraceae. The numbers at the head of each column represent *Arctomecon* alkaloids, each of which is identified in the footnote.

Genus	Alkaloid												
	A <sup>a</sup>			B				C			D		
	1	2	3	4	5	6	7	8	9	10	11	12	13
<i>Argemone</i>	x	x	x	x	x	x	x		x			x	
<i>Bocconia</i>	x	x		x	x	x	x						
<i>Chelidonium</i>	x	x		x	x	x	x						
<i>Dendromecon</i>	x	x				x	x						
<i>Dicranostigma</i>	x	x		x	x								
<i>Eschscholtzia</i>	x	x	x	x	x	x							
<i>Glaucium</i>	x	x	x	x	x	x	x		x			x	
<i>Hummelmannia</i>	x	x		x	x								
<i>Hylomecon</i>	x	x		x	x								
<i>Macleaya</i>	x	x		x	x								
<i>Meconella</i>		x											
<i>Meconopsis</i>	x	x	x			x							
<i>Papaver</i>	x	x	x	x	x	x	x		x	x			
<i>Platystemon</i>		x		x	x								
<i>Roemeria</i>		x											
<i>Romneya</i>		x		x	x	x			x				
<i>Sanguinaria</i>	x	x		x	x		x						
<i>Stylomecon</i>	x	x	x	x	x								
<i>Stylophorum</i>	x	x	x	x	x								

<sup>a</sup>Key: A - protopines, B - benzophenanthridines, C - tetrahydrobenzylisoquinolines, D - protoberberines, 1 - allocryptopine, 2 - protopine, 3 - cryptopine, 4 - chelerythrine, 5 - dihydrochelerythrine, 6 - sanguinarine, 7 - dihydrosanguinarine, 8 - sanguirubine, 9 - arnepine, 10 - reticuline, 11 - pseudolaudanine, 12 - tetrahydropalmatine, 13 - N-methyltetrahydropalmatine. Compiled from Preininger (1986), Raffauf (1970), Sternitz (1989), Willaman and Li (1970), and Willaman and Schubert (1961).

genera. The alkaloids of the Papaveraceae genera *Canbya* and *Eomecon* have yet to be studied; thus those genera are not included in Table 1. The alkaloids 12-methoxyalloycryptopine, pseudolaudanine, and N-methyltetrahydropalmatine are found in the Papaveraceae only in *Arctomecon* at this time. The tetrahydrobenzylisoquinolines and the protoberberines of *Arctomecon* are shared only with *Argemone* and *Romneya* (tetrahydrobenzylisoquinolines only) among the genera endemic to western North America (*Argemone*, *Dendromecon*, *Eschscholtzia*, *Platystemon*, and *Romneya*). The tetrahydrobenzylisoquinolines and the protoberberines are also shared with the genera *Glaucium* (European) and *Papaver* (tetrahydrobenzylisoquinolines only), a genus widespread in the Northern Hemisphere. It is interesting to note that protopine is found in all and alloycryptopine, chelerythrine, and sanguinarine in nearly all genera of Papaveraceae. According to Santavy (1970), sanguinarine-type benzophenanthridines are the most

widely distributed alkaloids in the Papaveraceae. As indicated in Table 1, *Meconella* and *Roemeria* are the only genera that do not contain at least one of the five benzophenanthridines reported in *Arctomecon*. *Dendromecon* and *Meconopsis* are the only genera in which sanguinarine is reported in the absence of chelerythrine; however, the results for *Dendromecon* are preliminary, and benzophenanthridines other than those reported in Table 1 (i.e., sanguinarine and dihydrosanguinarine) may be present in trace amounts (F. R. Sternitz, unpublished data, 1989). It is not surprising that the dihydro- analogues of benzophenanthridines (i.e., dihydrochelerythrine and dihydrosanguinarine) are reported only in the presence of the parent compounds. Among the *Arctomecon* alkaloids, 12-methoxyalloycryptopine, pseudolaudanine, and N-methyltetrahydropalmatine have not been reported elsewhere in the Papaveraceae. As stated earlier, 12-methoxyalloycryptopine is a new alkaloid reported only in *Arctomecon*. It is interesting that 12-methoxyalloycryptopine occurs in significant quantities in all species of *Arctomecon* but is absent in all other Papaveraceae genera. Other protopines are widespread in the Papaveraceae. We previously speculated (Raynie et al. 1990) that a new biosynthetic pathway for 12-methoxyalloycryptopine may be present in *Arctomecon*, evidenced by an accumulation of protopine-type alkaloids and a relatively low content of benzophenanthridines in *Arctomecon* relative to related genera. The absence of pseudolaudanine and N-methyltetrahydropalmatine in other Papaveraceae is not too surprising, since they are present in *Arctomecon* in minor amounts and in only one or two species. Due to the role of tetrahydrobenzylisoquinolines and tetrahydroprotoberberines as biosynthetic intermediates, it would not be unreasonable to expect the presence of pseudolaudanine and n-methyltetrahydropalmatine in other Papaveraceae genera in amounts too small to be detected.

#### ALKALOID DISTRIBUTION IN *ARCTOMECON* AND POSSIBLE IMPLICATIONS

Absolute quantities of endogenous alkaloids are expected to vary with such factors as stage of plant development, tissue considered, and environmental factors, as well as

TABLE 2. Tissue distribution of alkaloids found in *Arctomecon*.

Alkaloid	<i>A. humilis</i>				<i>A. californica</i>				<i>A. merriamii</i>			
PROTOPINES												
Protopine	C <sup>a</sup>	R	L	O	C	R	L	O	C	R	L	O
Allocriptopine	C	R	L	O	C	R	L	O	—	R	L	—
12-Methoxyallocriptopine	C	—	—	—	—	R	—	—	C	R	—	—
Cryptopine	—	R	—	—	—	—	—	—	—	—	—	—
BENZOPHENANTHRIDINES												
Unknown	—	R	—	—	—	R	—	—	—	R	—	—
Sanguinarine	—	R	—	—	—	R	—	—	—	R	—	—
Dihydrosanguinarine	—	R	—	—	—	R	—	—	—	R	—	—
Chelerythrine	—	R	—	—	—	—	—	—	—	—	—	—
Dihydrochelerythrine	—	R	—	—	—	—	—	—	—	—	—	—
Sanguirubine	—	R	—	—	—	—	—	—	—	—	—	—
Unknown	—	—	—	—	—	R	—	—	—	—	—	—
TETRAHYDROBENZYLISOQUINOLINES												
Arnepavine	C	—	—	O	—	—	—	—	—	—	—	O
Reticuline	C	—	—	O	—	—	—	—	—	—	—	—
Pseudolaudanine	—	—	—	—	—	—	—	—	—	—	—	O
PROTOBERBERINES												
N-methyltetrahydropalmatine	—	—	L	—	—	—	L	—	—	—	—	—
Tetrahydropalmatine	—	—	L	O	—	—	—	—	—	—	—	—

\*Key: C = capsule, R = root, L = leaf, O = other (primarily stalk, also flowers and buds). Compiled from Raynie et al. (1990)

genetic differences. For this reason, absolute statements concerning the alkaloid content of *Arctomecon* must be made with the warning that these statements may be only partially correct, since our determination of the alkaloid content of *Arctomecon* is best construed as a "snapshot in time" rather than a truly definitive study. This warning was articulated by Robinson (1979):

This ontogenic variation should be a warning to anyone who searches for a role of alkaloids in ecological interactions, for it is the alkaloid content at the exact time and place of any presumed interaction that must be determined. . . . For the field ecologist it is important to recognize that one population of a species may have a different alkaloid content than another population growing at a different location.

In an early study on the alkaloids of *A. californica*, Stermitz and Muralidharan (1967) reported that protopine and allocriptopine were present in approximately equal amounts, accounting for around 95% of the total alkaloid content. Muralidharan (1969) also reported that the total alkaloid content in *A. californica* was 0.4% and that, in addition to protopine and allocriptopine, at least three additional basic alkaloids and one quaternary alkaloid were present. However, these alkaloids were not identified. These results are similar to those we have reported (Raynie et al. 1990). In all species of *Arctomecon*,

divided by tissue type, allocriptopine and protopine combined to account for 60–100% of the total alkaloid content. With the exception of *A. californica* capsule and root tissues, allocriptopine is present at much higher levels than protopine, and, in *A. merriamii*, root tissue is the only significant source of protopine.

A general rule of alkaloid distribution in plants is that they tend to accumulate in actively growing tissues and latex vessels and that alkaloid content increases rapidly at the time of cell enlargement and vacuolization and then declines slowly during senescence (Robinson 1979). The alkaloid distribution in *Arctomecon* is presented by tissue type in Table 2. Our results for *Arctomecon* showed that the highest concentration of alkaloids was in the capsule and the lowest was in the root, although for *A. californica* the amount of total alkaloids was more evenly distributed among tissues. Although the alkaloid content of the root material was lower than in other tissues, root tissue was found to contain the greatest variety of different alkaloids, and the benzophenanthridine alkaloids were limited exclusively to root tissue. Other generalizations from our limited sample include the facts that the allocriptopine/protopine ratio is greater in the leaf and stalk tissues than in capsule and root tissues and that *A. californica* and

*A. merriamii* are much simpler, in terms of alkaloid makeup, than *A. humilis*. The tetrahydrobenzylisoquinolines and tetrahydroprotoberberines, possible biosynthetic intermediates, were found scattered in trace amounts in all tissues except the root. However, conclusions cannot be drawn from this observation, since it is well known that the site of alkaloid accumulation is often not the site of synthesis.

Robinson (1979) has suggested that alkaloids in leaf and stem tissue render those tissues less palatable to herbivores. A population of over 400 individuals of *A. humilis* has been inventoried at four- to six-week intervals (and with greater frequency during the flowering season) from February 1987 to the present (Nelson 1989). Other *A. humilis* populations were observed less regularly during this same time period. At each observation period, we searched for evidences of herbivore predation in all individuals. Herbivory was found to be uncommon in *A. humilis* plants, and such herbivory as was noted was attributed to two sources: rabbits and insects. In the late summer and fall of 1987, considerable use by rabbits was observed. Rabbit herbivory has been observed in only a few isolated incidents since that time. Typically, leaves were clipped near the base, and a pile of "harvested" leaves usually occurred near the plant. In all cases clipped leaves were accompanied by rabbit feces located within 40–50 cm of the affected plant. Of the 84 plants exhibiting herbivory, 82% died. While overall mortality in the population was high (58%) during 1987, mortality among the rabbit-damaged plants was significantly greater than among ungrazed plants. Nevertheless, it is not possible to attribute a cause-and-effect relationship to such data. While it may seem apparent that herbivory was the cause of mortality, it is possible that decadence of the foliage rendered the tissue more palatable to rabbits.

Robinson (1979) also noted the role of alkaloids, especially steroidal alkaloids, in plant-insect interactions. Insect damage to *A. humilis* was minimal on the study plot throughout the three years of observation. The most commonly observed insect was a small mealybug tentatively identified as *Spilococcus atriplicis* at the California Department of Food and Agriculture (Riley Nelson,

personal communication, 1990). The organism itself is very minute and rudimentary, unable to fly or walk. Its infestation is marked by a cottony mass that shelters a few of the insects at the base of individual leaves. The infection sites are buried well into the thatch of leaves. The first infestations of this type were noted in April 1989. Twenty plants, in two subpopulations, harbored the insect. In July only 14 plants displayed the cottony masses. Only 8 plants harbored the insects in October. The number of infected plants increased to 13 in December 1989. Effects of the insect on *A. humilis* plants appear to be variable, but in most cases an increase in the amount of decadent leaf tissue was observed. *Spilococcus* spp. are sucking insects known to feed on plant juices. Affected leaves gradually turn brown and abscise. Of the 20 plants infected in April 1989, 3 had died by December; each of these individuals had exhibited less than 30% decadent tissue at the first sign of infestation. Only 4 of the 20 infected plants exhibited greater than 50% decadent tissue in April, but 12 had greater than 50% dead tissue by December. The condition of three plants seemed to improve after infestation. Infestations moved from plant to plant through time; only 7 of the 20 plants infected in April still showed signs of infestation in December.

McKenzie (1967) notes that the Southern California mealybug (*S. atriplicis*) infects *Baccharis* spp., *Eriogonum inflatum*, *Pleuchea sericea*, *Haplopappus* spp., and *Eriogonum* spp. in California and *Atriplex canescens* in New Mexico. To our knowledge, none of these hosts are reported to contain significant amounts of alkaloids. However, *Spilococcus* is morphologically similar to the mealybug genera *Phenacoccus* and *Pseudococcus*. *Phenacoccus eschscholtziae* and *Pseudococcus obscurus* are both known to infect the California poppy (*Eschscholtzia californica*).

Mealybugs are known to have a host of symbiotic relationships with various ants (McKenzie 1967). Seed-offering experiments (D. R. Nelson and K. T. Harper, unpublished data, 1989) have shown that ants appear to be the principal biological dispersal agent of *A. humilis* seeds. Thus ants are regularly associated with *A. humilis* plants, and ants have been reported to sometimes move mealybugs from one host plant to another (McKenzie 1967). It is thus possible that ants spread the

infestation from plant to plant across the barren gypsum soil.

### CONCLUSIONS

*Arctomecon* species are similar to most other Papaveraceae genera in respect to protopine and benzophenanthidine alkaloids, but they also contain tetrahydrobenzylisoquinoline and protoberberine alkaloids that have not been reported for most other poppy genera. The tetrahydrobenzylisoquinoline-type alkaloids are also known from the genera *Argemone* (primarily western North American), *Glaucium* (European), *Papaver* (circumboreal), and *Romneya* (southern California and adjacent Mexico). The protoberberine alkaloids are known only for the genera *Argemone* and *Glaucium* in the Papaveraceae. The diverse alkaloid content of the *Arctomecon* species may be related to the light herbivory observed on these evergreen species in the desert environment.

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SCANNING ELECTRON MICROSCOPIC STUDY OF THE MALE GENITALIA  
OF THE NORTH AMERICAN ALDERFLY GENUS *SIALIS*  
(MEGALOPTERA: SIALIDAE)

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**ABSTRACT.**—Scanning electron micrographs are presented for 14 species of the North American alderfly *Sialis*: *americana*, *arvalis*, *californica*, *contigua*, *cornuta*, *hamata*, *iola*, *joppa*, *mohri*, *nevadensis*, *occidens*, *rotunda*, *vagans*, and *velata*. Male genitalic characters are described for use in species identification.

**Key words:** *Sialis*, *Sialidae*, *Megaloptera*, *Neuroptera*, SEM, alderflies.

There are currently 24 biological species of *Sialis* recognized from North America (Ross 1937, Townsend 1939, Flint 1964, Whiting 1991). Ross (1937) was the first to illustrate and compare the genitalic characters among many species of alderflies. While both Canterbury (1978) and Evans (1971) have concentrated studies on the larvae of North American *Sialis*, since the work of Ross (1937) no serious study has compared the male genitalia among all the North American species. A clear understanding of genitalic characters is essential for proper species identification; consequently, there is a critical need to re-examine male genitalia within the genus *Sialis*.

During a study of the phylogenetic relationships among the North American species of *Sialis*, I used electron microscopy to evaluate minute genitalic characters with greater clarity. The purpose of this paper is to present the electron micrographs and brief descriptions of the species groups and the diagnostic genitalic characters for 14 species of *Sialis*. Because the micrographs better illustrate many of the structures used by Ross (1937) in his key to the North American species of *Sialis* and also show many new and important characters, this paper should be useful for species identification.

METHODS AND MATERIALS

Over 4000 specimens of North American adult *Sialis* were dissected and examined with

a light microscope to evaluate genitalic characters among many individuals from the 14 different species. From each species a male specimen was specially dissected for SEM study. Collection data for the specimens used in this study are as follows: *americana* (Rambur): WISCONSIN, Grant Co., Wyalusing State Park, 26 June 1957, A. L. Thorne; *arvalis* Ross: CALIFORNIA, Santa Clara Co., San Jose, Alum Rock Park, 19 April 1987, N. D. Penny; *californica* Banks: CALIFORNIA, Napa Co., Napa, 2 May 1948, H. P. Chandler; *contigua* Flint: VIRGINIA, Smyth Co., North Fork of Holston River, Route 42, near junction Route 633, 5 May 1981, B. C. Kondratieff; *cornuta* Ross: CANADA, Alberta, Konanaskis beaver ponds near Lusk Creek, 6 May 1969, T. G. Leischner; *hamata* Ross: UTAH, Wasatch Co., Bryants Fork Creek near Strawberry Reservoir, 6 June 1988, M. F. Whiting; *iola* Ross: VIRGINIA, Montgomery Co., Isaac Walton Park Pond, 11 May 1977, S. Mudre; *joppa* Ross: NEW HAMPSHIRE, Coos Co., Ellis River, Hwy. 16, Pinkham Notch, 7 June 1980, Baumann & Earnshaw; *mohri* Ross: MINNESOTA, St. Louis Co., Lake Jeanette, 22 June 1964, H. B. Mills; *nevadensis* Davis: CALIFORNIA, El Dorado Co., Blodgett Forest, 31 May 1969, D. Levin; *occidens* Ross: CALIFORNIA, Mariposa Co., Miami Ranger Station, 23 May 1942, S. H. Benedict; *rotunda* Banks: OREGON, Klamath Co., Wood River Spring, 12 June 1964, J. Schuh; *vagans* Ross: VIRGINIA, Brunswick Co., Greef Creek, U.S. 58 bridge,

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25 April 1982, B. C. Kondratieff; *velata* Ross: MINNESOTA, Louis Co., Eagle Nest Lake, 1 June 1959, W. V. Balduff.

For specimens preserved on pins, the last four segments of the abdomen were removed and placed in a warm solution of 10% KOH (potassium hydroxide) for 20 minutes until the abdominal cuticle was softened and the genitalia became clearly visible. Specimens preserved in alcohol did not require treatment with the KOH solution. The abdomens were placed in an ultrasonic cleaning unit for 15 seconds to dislodge any foreign material from their surfaces. They were then removed from the cleaning unit and further dissected as needed to expose the genitalia. The abdomens were serially dehydrated in a series of ethanol concentrations (70%, 80%, 90%, 100% for 15 minutes each) and then placed in a solution of acetone over calcium sulfate crystals (2 hours). They were next critical-point-dried, mounted on aluminum stubs, and gold-plated in a Polaron DC sputter coater in preparation for SEM examination at 10 kv.

#### GENITALIC STRUCTURES

SEM analysis illustrates with greater clarity the genitalic structures useful for species identification within the *Sialis*. Ross (1937) used purely descriptive names for *Sialis* genitalia. Since a definite homology for the genitalia of alderflies with those of other insect groups has not yet been proposed, and since all other species descriptions of *Sialis* have relied upon these same names (Townsend 1939, Flint 1964, Whiting 1991), for the sake of consistency this paper will use Ross's descriptive names.

The male genitalia of *Sialis* consist of three major parts: the lateral, genital, and terminal plates. The lateral plates are a pair of ovoid plates just posterior to sternum 9 (Fig. 1c). These plates are contiguous mesally in most species and covered with dense setae. In some species these plates are modified into large arms bearing coarse setae (Fig. 9). The genital plate is a single sclerotized plate found posterior to the lateral plates and anterior to the terminal plates (Fig. 1b). In many species this plate is divided into two major arms that vary in size and length among species. Basally, the genital plate is either fused to the basal portion of the terminal plate (Infumata

species group) or attached to a membranous wall. Because the shape of the genital plate is highly species specific, it is the most diagnostic character for determining species identity. However, because it is also the smallest genitalic structure and is usually concealed beneath the terminal and lateral plates, it is often the most difficult structure to observe. The terminal plate is a single plate on the caudal end of the abdomen circling the borders of the anus (Fig. 1a). The dorsal margin of this plate is reduced while the ventral margin is often cleft, bilobed, or modified into single or double arms. Every species and species group of *Sialis* has a unique combination of modifications of these genitalic structures, making species identification rather simple and straightforward.

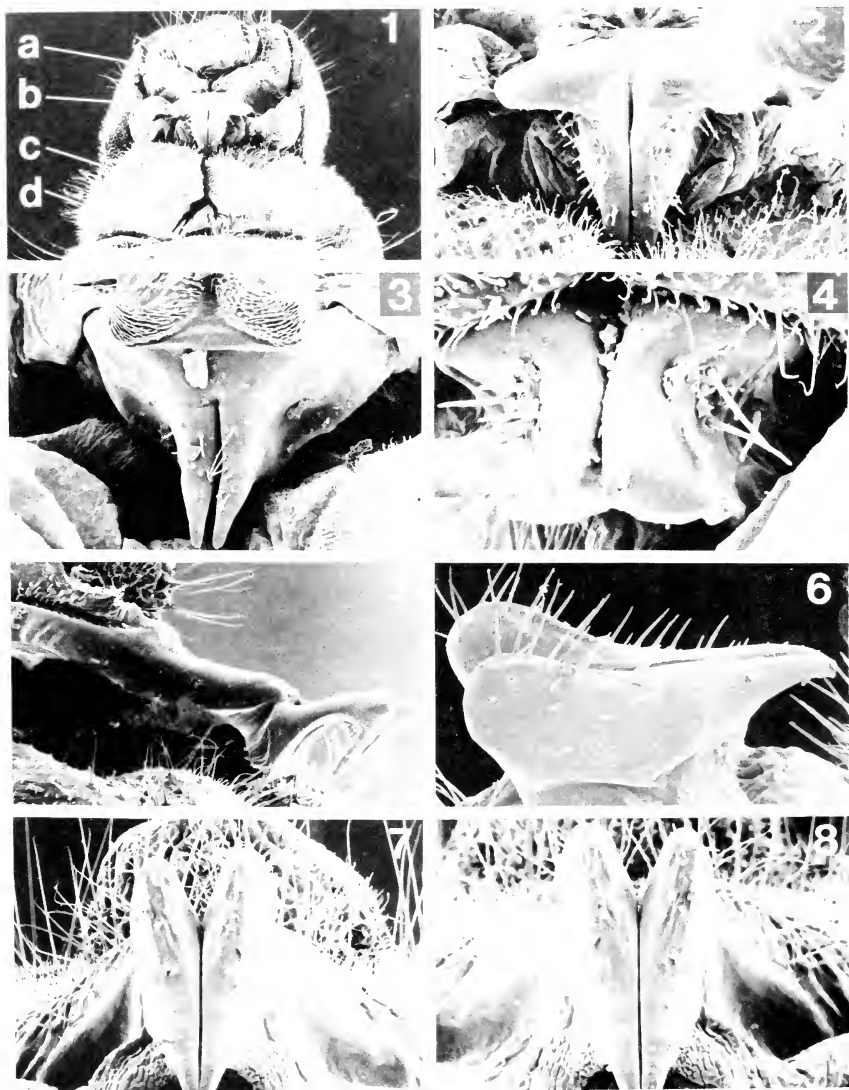
#### CALIFORNICA GROUP

The California species group consists of three eastern species (*driesbachi* Flint, *iola* Ross, and *joppa* Ross) and six western species (*arvalis* Ross, *bilobata* Whiting, *californica* Banks, *cornuta* Ross, *hamata* Ross, and *occidens* Ross). This group is characterized by a conspicuous bulbous evagination on tergum 9, reduced sternum 9, and a greatly reduced genital plate clothed sparsely with setae.

*Sialis californica* Banks.—From a lateral aspect (Fig. 6), the genital plate is saddle-shaped and lobed behind the point of basal attachment. The size of this lobe appears to vary in different populations, with a tendency to gradually decrease as the distributions become more northern. From the dorsal aspect, the arms of the genital plate are contiguous mesally and moderately covered with setae (Fig. 8).

*Sialis occidens* Ross.—The basal portion of the genital plate projects above the apex of the terminal plate (Fig. 1). The genital plates are superficially shaped like *S. californica* except that the basal portions are flanged laterad and devoid of any setae (Fig. 2) and the genital plate is not lobed behind the point of articulation with the basal membrane.

*Sialis hamata* Ross.—The ventral margin of the terminal plate bears a dark, elongate sclerotization that projects from the base of the terminal plate and hinges basally to the genital plate (Fig. 5). The length of this neck is reduced in northern populations. The genital



Figs. 1-8. Male genitalia of *Sialis* spp.: 1, *occidentens* Ross, a. terminal plate, b. genital plate, c. lateral plate, d. sternum 9 (ventral); 2, *occidentens* Ross, genital plate (ventral); 3, *cornuta* Ross, genital plate (ventral); 4, *arvalis* Ross, genital plate (ventral); 5 and 7, *hamata* Ross, genital plate (anterolateral and ventral); 6 and 8, *californica* Banks, genital plate (lateral and ventral).

plate is lobed ventrally and apically recurved, giving a distinct barbed-hook appearance. That the caudal aspect of the genital plate in *S. hamata* (Fig. 7) is identical in shape with the dorsal aspect of the genital plate in *S. californica* (Fig. 8) suggests that these may be sister species.

*Sialis cornuta* Ross.—The terminal plate has the apical margins cleft, and each cleft lobe is produced into swollen bulbs that diverge laterally (Fig. 3). The genital plate is broad and convex and mesally bears a pair of straight, stocky arms (Fig. 3).

*Sialis arvalis* Ross.—The genital plate is hinged to the apical margins of the terminal plate and is attached ventrally to a clear, sac-like membrane. The genital plate is strongly flanged basally and is apically produced into a pair of short fingers (Fig. 4). The terminal plate bears a pair of large lobes apically (not visible in Fig. 4).

*Sialis joppa* Ross.—The genital plate is broad but slightly constricted on the lateral margins. Apically, the genital plate is produced into a pair of short fingers (Fig. 15). Lateral to the genital plate and posterior to the terminal plates are a pair of clear, membranous extrusions.

*Sialis iola* Ross.—The genital plate is elongate, rectangular, and apically produced into a pair of short fingers. The terminal plate has the apex narrow and tapering to a blunt point (not visible in Fig. 16).

#### AEQUALIS GROUP

The Aequalis group consists of two western species (*nevadensis* Davis and *rotunda* Banks) and three eastern species (*aequalis* Banks, *contigua* Flint, and *vagans* Ross). This group is characterized by a large, relatively unspecialized genital plate devoid of setae and a large, flaplike sternum 9. Tergum 9 rarely bears a bulbous evagination.

*Sialis rotunda* Ross.—The genital plate is subdivided into two concave halves that serve as receptacles for the apical portion of the lateral plates (Fig. 9). Two stocky genital hooks arise from the median evaginated ridge on the genital plate. These hooks run parallel and are moderately recurved ventrad (Fig. 10). The terminal plate is quadrate and only slightly cleft (Fig. 9). The lateral plates are produced into a pair of blunt arms

covered with dense setae on the dorsal margins (Fig. 9).

*Sialis nevadensis* Davis.—This species bears a very large, subrectangular genital plate that is slightly convex. The genital plate bears a small pair of short fingerlike projections on its upper surface (Fig. 13). Beneath each finger is a membranous region which appears white under light microscopy.

*Sialis vagans* Ross.—The genital plate is large and subrectangular from a lateral aspect (Fig. 11). Extruded mesally is a single arm that becomes strongly bulbous apically (Fig. 12). Two small, pointed fingers are produced on the apical portion of this bulb.

*Sialis contigua* Flint.—Basally, the genital plate is similar in size and shape to *S. vagans*. However, the median arm is narrower and the apical fingers are longer and diverge laterally from the medial point of attachment (Fig. 14). The terminal plate is U-shaped with the arms of the U closely appressed.

#### INFUMATA GROUP

The Infumata species group comprises eight species: *concava* Banks, *hasta* Ross, *infumata* Newman, *itasca* Ross, *mohri* Ross, *nina* Townsend, *spangleri* Flint, and *velata* Ross. All of these species are eastern or mid-western except *velata*, which occurs throughout North America. This group is characterized by a shield-shaped genital plate bearing a long pair of whiplike arms. The genital plate is completely fused to the basal portion of the terminal plate and is devoid of setae. The lateral plates are elongate, sternum 9 is moderately large, and tergum 9 lacks a bulbous evagination.

*Sialis velata* Ross.—The genital arms are long and curve 90 degrees before attaching to the genital plate. These arms fuse together before reaching the genital plate (Fig. 17) and bear a median lobe that is nearly one-half the length of the arms. The terminal plate, quadrate and slightly cleft, is basally fused to the genital plate.

*Sialis mohri* Ross.—The genital arms are long but stockier than *S. velata*. The median lobe of the genital arms is absent (Fig. 18). The terminal plate bears a pair of long, heavily sclerotized arms that converge medially (not visible in Fig. 18).



Figs. 9–14. Male genitalia of *Sialis* spp.: 9, *rotunda* Banks, lateral, genital, and terminal plates (ventral); 10, *rotunda* Banks, genital plate (ventral); 11 and 12, *vagans* Ross, genital plate (lateral and ventral); 13, *nevadensis* Davis, genital plate (lateral oblique); 14, *contigua* Flint, genital plate (ventral).

#### AMERICANA GROUP

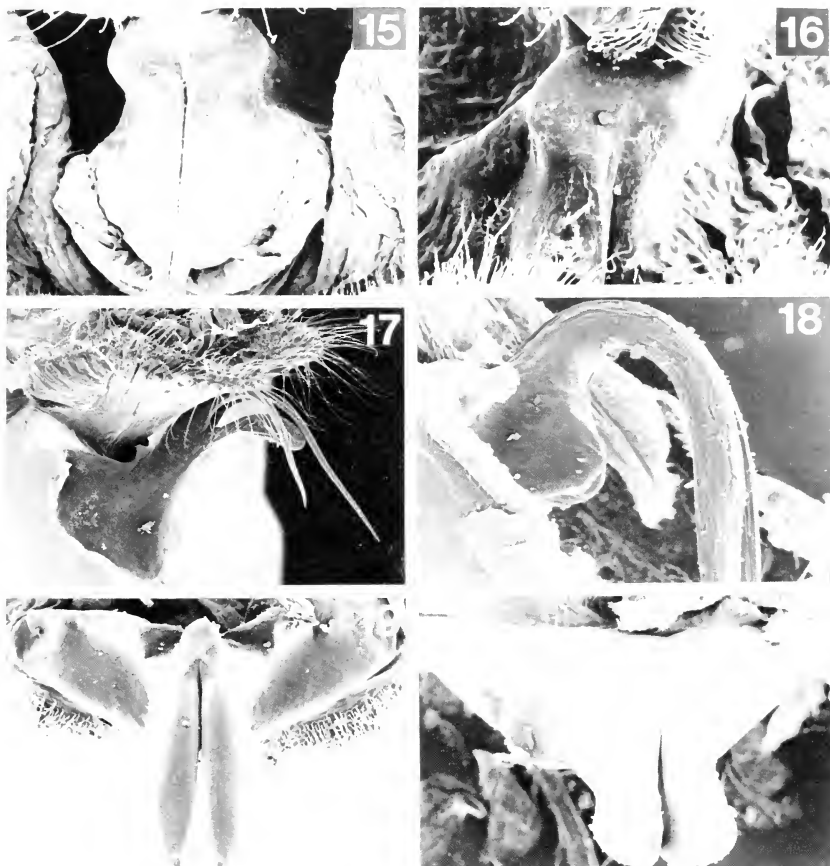
The Americana species group consists of two eastern species: *americana* (Rambur) and *glabella* Ross. This group is distinguished by the large, unspecialized genital plate, moderately large sternum 9, and the unique, light red coloration of the body. The genital plate lacks setae, and sternum 9 lacks a bulbous evagination.

*Sialis americana* Rambur.—The genital plate is triangular and mesally bears a pair of long, broad arms (Figs. 19, 20). These arms

run nearly parallel but diverge slightly laterally. The genital plate and arms do not bear setae.

#### DISCUSSION

The higher magnification and greater depth of field available make SEM a valuable tool for investigating evolutionary and taxonomic relationships within the *Sialis*. SEM analysis of North American *Sialis* has revealed that the genital structures are clearly diagnostic for all



Figs. 15–20. Male genitalia of *Sialis* spp.: 15, *joppa* Ross, genital plate (ventral); 16, *iola* Ross, upper half of genital plate (ventral); 17, *velata* Ross, genital and terminal plate (lateral oblique); 18, *mohri* Ross (lateral); 19 and 20, *americana* (Rambur) genital plate (ventral and dorsal).

14 species studied and that these structures are the key to understanding evolutionary relationships within the Sialidae.

All species identifications of adult Sialidae in North America have relied upon the key published by Ross (1937). After working with this key for several years, I have found that some couplets are ambiguous because they rely on characters that are either obscure or artificial. Compounding this problem are sketchy drawings that only partially reflect the actual structure. SEM analysis and light

microscopy have revealed that there are characteristics better suited for species identification than those used in the key of Ross. Some of these characters are illustrated and outlined above. Therefore, use of these micrographs in conjunction with Ross's key will aid in more accurate identification of *Sialis* species.

#### ACKNOWLEDGMENTS

I thank Wilford M. Hess, James V. Allen, and Connie Swenson of the Electron Optics

Laboratory at Brigham Young University for their help with technical and critical aspects of scanning electron microscopy. I also thank Richard W. Baumann and Stephen L. Wood for reviewing early drafts of this manuscript.

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NEW SPECIES OF *SIALIS* FROM SOUTHERN CALIFORNIA  
(MEGALOPTERA: SIALIDAE)

Michael F. Whiting<sup>1</sup>

**ABSTRACT.**—*Sialis bilobata* is described as a new species of the alderfly family Sialidae from Los Angeles County, California. A brief description of the species, illustrations, and diagnosis that compares it with *Sialis arvalis* Ross are provided.

**Key words:** *Sialis*, *Sialidae*, *Megaloptera*, *Neuroptera*, *alderflies*, *aquatic insects*.

Alderflies are relatively rare semiaquatic insects found as adults along the margins of streams and lakes. Currently all alderflies in North America are placed in the genus *Sialis*. There have been 23 species of *Sialis* described from North America (Ross 1937, Townsend 1939, Flint 1964). During a study of phylogenetic relationships of the North American alderflies, I found an undescribed species among material loaned from Southern California. This new species is very interesting because it helps unravel the phylogenetic history of the Californica species group in western North America.

DIAGNOSIS

*Sialis bilobata* is most closely related to *S. arvalis* Ross and has been identified as such by previous workers. The terminal plate of *S. bilobata* swells apically to produce two large bulbous lobes that diverge laterally, whereas in *S. arvalis*, the apical portion of the terminal plate is only slightly swollen, and the small bulbs do not diverge but are contiguous mesally. From a lateral aspect (Fig. 1), the apical portion of the terminal plate in *S. bilobata* is more than twice as wide as the basal portion where swelling begins; in *S. arvalis* it is only slightly wider than the basal region. The genital plate in the two species is similar in shape, but in *S. bilobata* it is twice as large as in *S. arvalis*. In *S. bilobata* the plate is 0.144–0.154 mm in length; in *S. arvalis* it is 0.060–0.077 mm in length.

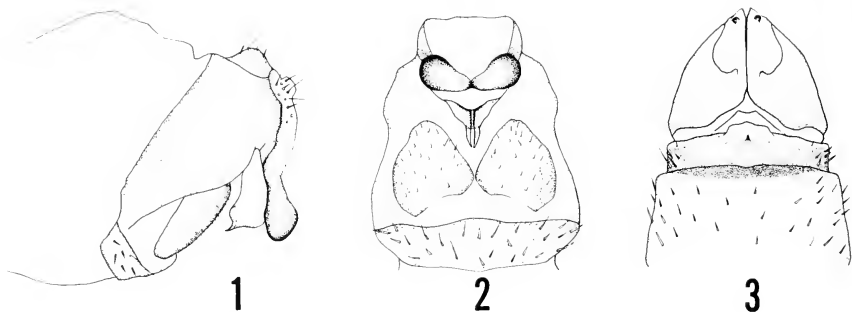
*Sialis bilobata* is distributed along the southern Pacific Coast and is known only from Ventura and Los Angeles counties in California. *S. arvalis* is distributed along the Pacific Coast from Douglas Co., Oregon, south to Santa Barbara Co., California.

*Sialis bilobata*, n. sp.

**MALE.**—Body length 10.5–12.0 mm; wing length 9.2–10.0 mm. Head, body, and appendages black except: raised lines and dots on head and narrow ring around eye, yellowish; vertex clothed with abundant short setae; legs shading to brown; wings dark brown, slightly lighter towards apex. Sternum 9 narrow and bandlike, with sparse, short setae (Fig. 2). Lateral plates triangular, with middle portions closely appressed on meson. Genital plate small, quadrate, heavily sclerotized, and bearing short setae. Genital plate with a pair of short, closely appressed genital hooks attached basally which taper to a fine point. Genital plate basally attached to a clear, saclike membrane; membrane fused to ventral surface of terminal plate. Terminal plate U-shaped with apical margins swollen into two bulbous lobes diverging laterally (Fig. 2). From lateral aspect, these bulbs protrude caudally further than any other genital structure. Tergum 9 heavily sclerotized with a large extruded dorsal hump bearing coarse setae.

**FEMALE.**—Body length 12–14 mm; wing length 10.0–11.3 mm. Color and general structure as in male. Sternum 7 heavily sclerotized

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Figs. 1-3. Genitalia of *Sialis bilobata* n.sp.: 1, ♂ (lateral); 2, ♂ (ventral); 3, ♀ (ventral).

and clothed with sparse setae (Fig. 3). Sternum 8 tilted, base depressed and apex raised; mesal portion slightly depressed longitudinally and bearing a heavily sclerotized spine; setae only moderately long mesally but longer laterally. Apical portion of segment bears a small, round depression on meson. Sternum 9 membranous but fairly rigid, forming a wide V.

**TYPE MATERIAL.**—The male holotype was collected from Brents Mountain Crags, Los Angeles Co., California, 20-V-1939, collector unknown; the female allotype is from Santa Ynez Canyon, Los Angeles Co., California, 30-III-57, V. A. Tucker. Paratypes are from the following localities: one male from Tapia Camp, Santa Monica Mountains, Los Angeles Co., California, 22-III-47, L. M. Martin; one male from Santa Ynez Canyon, Los Angeles Co., California, 30-III-57, V. A. Tucker; and one male from Ventura Co., Sespe Creek, 5 miles north of Fillmore, I-IV-1981, R. W. Baumann & J. A. Stanger.

The holotype, allotype, and all paratypes except the Sespe Creek specimen are at the Los Angeles County Museum. The remaining paratype is in the Brigham Young University collection.

#### DISCUSSION

In Ross's taxonomic key to the Sialidae (1937), *S. bilobata* would come out in couplet 19b. with *S. arvalis*, but the two can be separated by the characters given above. According to the preliminary species groups

as described by Ross (1937), *S. bilobata* is in the Californica species group. Based on phylogenetic analysis of morphological characters, *S. bilobata* appears to be very closely related to *S. arvalis*. Indeed, only these two species share the character of a uniquely shaped genital plate resting on a saclike membrane. That the distributions of both species are along the Pacific Coast further indicates that these species diverged from a common ancestor.

Evans (1971) designated an allotype for *S. arvalis* from a female collected from California, Ventura Co., Los Padres National Forest, Sespe Creek, Sespe Gorge Campground, Hwy 33, 3-VI-1968, E. D. Evans. Because this specimen was collected from a locality in which *S. bilobata* is known, it is probable that this allotype is a female *S. bilobata*. Because the females of these species are identical in appearance, no known morphological data can be used to support or refute this supposition. Nevertheless, based on the distinct distributional range of the species, it is suggested that the allotype designation for *S. arvalis* be withdrawn.

#### ACKNOWLEDGMENTS

I thank Richard W. Baumann for helpful suggestions and Stephen L. Wood for reviewing early drafts of this manuscript. Thanks are also extended to Charlie Hogue at the Los Angeles County Museum for the loan of specimens and to Sun Yung Kim for making the illustrations.



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## UNUSUAL FORM OF *OPUNTIA RAMOSISSIMA* ENGELMANN

Allan R. Taylor<sup>1</sup>

**Key words:** *Opuntia ramosissima*; diamond cholla; Clark County, Nevada; Spring Mountains, Nevada; Lee Canyon, Nevada; Kyle Canyon, Nevada; dwarf cholla.

An interesting and evidently unique population of *Opuntia ramosissima* Engelmann (diamond cholla) has recently been observed in the middle reaches of Lee Canyon, in the Spring Mountains of Clark County, Nevada. The population was first noted at its upper limit, at around 5000 feet. Subsequent investigation shows that the range of this particular population is entirely west of Highway 93, between 3800 and 5300 feet on both sides of State Highway 156.<sup>2</sup>

This form of *O. ramosissima* is decidedly dwarf, as might be expected of a low-altitude plant somehow translocated to an elevation higher than the norm for the taxon. (Benson 1982 indicates 3000 feet as the upper limit of *O. ramosissima*.) The plant is low, even a mat-former; to describe it as a cactaceous *krumholz* would not be amiss.

If the morphology and other traits of the plants in this interesting population should prove to be different enough to warrant varietal status, I would suggest that names denoting low, small, or dwarf would all be appropriate for the form.

The plants tend to be only one or two joints tall (Fig. 1), but with abundant, rather tightly packed branches. Younger plants usually have heavy yellow-brown spination, but the older plants, sinuous and very woody, are almost entirely naked. The color of the joints is typically amethyst purple, although collected plants growing in pots in the greenhouse are pale green.

Clumps were encountered in habitat undoubtedly many years old; numerous dead clumps were also noted, invariably very old

plants. Plants, both living and dead, are sparse until around 5000 feet, when they become more abundant.

Reproduction appears to be sexual, but no very small seedlings were encountered. The clumps are almost always in the open; thus, it is not likely that the plant requires the aid of a nurse plant to germinate and become established.

Companion plants are those that are characteristic of the eastern Mojave Desert: *Yucca schidigera*, *Larrea tridentata*, *Echinocereus engelmannii*, *Echinocactus polycephalus*, and *Malva* ssp. at the lower limit of the plant's distribution, progressing upward through *Opuntia acanthocarpa*, *O. multigeniculata*, *Tetrademia* ssp., *Chrysothamnus* ssp., *Atriplex* ssp., and *Ephedra* sp., with *Coleogyne ramosissima* and *Yucca brevifolia* var. *jaegeriana* dominant at the upper limit. *Coryphantha vivipara* var. *rosca*, which is relatively abundant in the higher reaches of the canyon, barely overlaps with *O. ramosissima* at the latter's upper limit. Of note also is that *Opuntia basilaris* occurs throughout the range of *O. ramosissima*, from the lowest elevations to the highest at which the taxon occurs.

Because individuals from this population have not been grown as yet under controlled conditions, it is not known whether the dwarf habit of the plants is an environmentally induced or a genetic trait. (Preliminary indications are that the size and form of the plant are genetically determined.) Cuttings from the population survived -25 F under snow in Boulder, Colorado, during the unseasonal cold of February 1989; so it appears likely

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<sup>2</sup>These interesting plants are not abundant in the area investigated. For example, when one stands at the location of one plant, it is unusual to see more than three or four other plants in the surrounding area. On the other hand, it is not rare either—many plants were discovered in the fifty or so acres surveyed.

Collection should be avoided, and it is indeed not necessary. I have supplied propagation material to the Nut House Nursery at Littlefield, Arizona, where interested persons can purchase established cuttings.

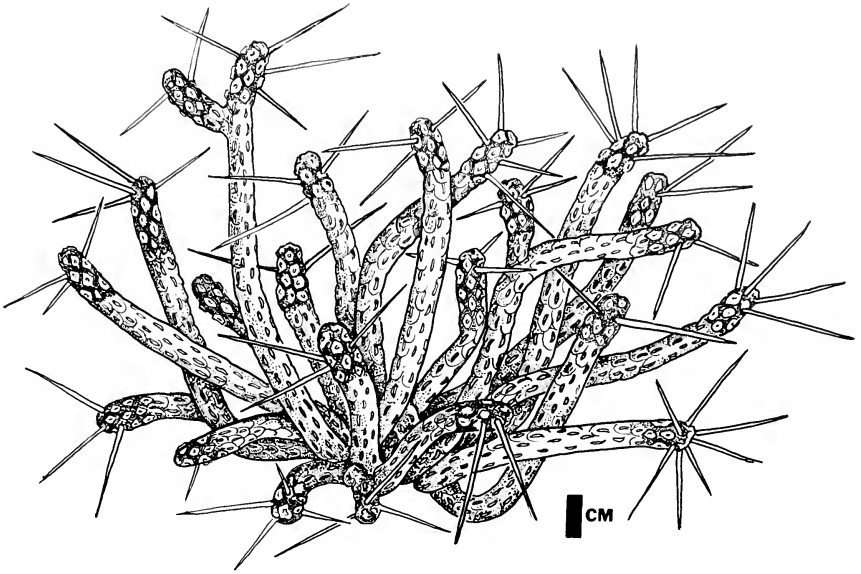


Fig. 1. *Opuntia ramosissima* Engelm.

that the high-altitude form has greater frost tolerance than those from the more typically low-altitude habitats favored by this taxon.

Still to be determined is the complete range of this form: it would be surprising if it did not occur elsewhere in the vicinity. An obvious place to look is nearby Kyle Canyon, but appropriate elevations should be checked throughout the Spring Mountains and other ranges of southern Clark County.

#### ACKNOWLEDGMENTS

I thank Kaye Thorne, Brigham Young University Herbarium, for the illustration of *O. ramosissima* Engelm.

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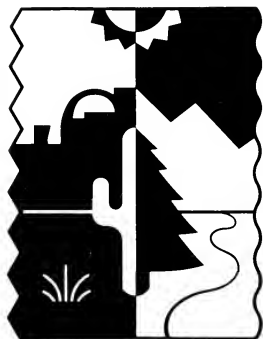
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